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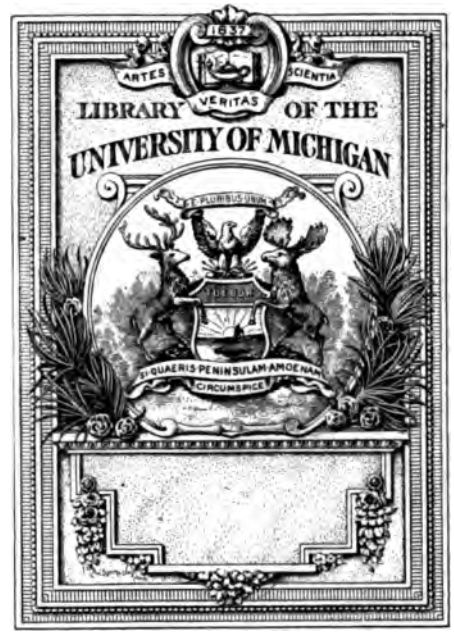
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UNIVERSITY OF TORONTO STUDIES

PSYCHOLOGICAL SERIES

EDITED BY

A. KIRSCHMANN

VOL. II.

PUBLISHED BY THE LIBRARIAN OF THE
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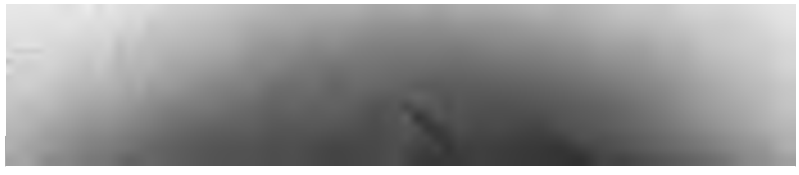

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THE CONCEPTION AND CLASSIFICATION OF ART

FROM A PSYCHOLOGICAL STANDPOINT

BY

OSWALD KÜLPE

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THE CONCEPTION AND CLASSIFICATION OF ART

(FROM A PSYCHOLOGICAL STANDPOINT)

In his very suggestive article on "Conceptions and Laws in Æsthetics"* Professor Kirschmann has pointed out the necessity of defining æsthetic conceptions on the basis of a thorough analysis of the phenomena concerned. The justification of such a demand can be shown not only by the examples which he selects from general æsthetics, but also in the realm of special æsthetics, where the confusing multitude of expressions and distinctions obstructs sure and direct progress towards general knowledge. Thus in the following discussion an attempt is made to contribute, critically and positively, to the elucidation of the question concerning the nature and forms of art. Since art and its branches might also be treated from other standpoints, such as that of the historian or of the technician, it may be stated in advance that the argument will here be confined to considerations from psychologico-æsthetical points of view. Here the products of art will only be dealt with in so far as they are æsthetically observed and judged, and as far as they are subject to the laws, measures and suppositions which scientific æsthetics develops.

*University of Toronto Studies, Psychological Series, Vol. I, pp. 179 *et seq.*

I.

THE CONCEPTION OF ART.

In a proper definition a statement is required of the *genus proximum* and the *differentia specifica*, through which all general and all characteristic attributes of the conception to be defined are determined. Therefore we shall have to examine some widely different definitions of the conception of art and determine whether they satisfy these conditions. In our criticism we shall abide by the prevailing usage of the language (believing that arbitrary deviation therefrom is useless), and by the logical demand that contradiction among the conceptions employed is to be avoided.

1. Art is the product of genius—according to Kant and Schopenhauer. In this definition the conception of "the product" is obviously the *genus proximum*, whilst the addition "of

genius" forms the *differentia specifica.* By the characterization of him who has created the product, the work of art is distinguished from other real and possible objects of the same kind. The conception of product is quite appropriate to serve as *genus proximum* for art, since doubtless an attribute which is valid for all art is thereby determined, viz. to be a product, a work of living beings. In this definition it is stated at the outset that art is not found in the same way as we find stars and clouds, mountains and valleys, organisms and minerals; but that it is made, produced by men. On the other hand the *differentia specifica* of the definition proves quite insufficient. (*a*) If the question be asked whether genius produces nothing but works of art, we must obviously answer no, for Leonardo da Vinci and Dürer, for example, have done scientific work as well. Accordingly a further determination of the products of genius is required to determine unambiguously the limits of art. (*b*) If the further question be put whether a genius is necessary to produce a work of art, the answer must again be given in the negative. For as a rule this title of honour is reserved for the most important and original of artists, while in the production of works of art more modest talent is also acknowledged. Therefore if our definition is too wide from the standpoint (*a*), since it does not confine itself to works of art, it is too narrow from the standpoint (*b*), since it does not include all art. (*c*) If we try to escape these difficulties by defining genius as an agency in the production of works of art, we fall into the error of a *circulus in definiendo*, using in the definition the conception to be defined.

2. *Art is free activity of the fantasy creating the perfect in form and content*—after Köstlin. Here the *genus proximum* is "action of fantasy," the attributes of which form the *differentia specifica.* There are strong objections to this definition also:—(*a*) The *genus proximum* must be discredited at once. If all art were mere action of fantasy then the centre of gravity would rest in this action, and not in its product, in which other factors may occur. The objective appearance of art as it presents itself universally would fall into the background, and the determination of the conception would be directed to a primitive stage of its origin. Now, to us who observe and appreciate, art is always manifested

as a finished work, and the inference from the effect to the cause is of acknowledged uncertainty. (*b*) The *differentia specifica* also cannot be regarded as a happy choice. It may fairly be doubted whether in a portrait a *free* activity of fantasy is present or finds expression. Further, the limitation of art to the perfect in content and form must be rejected as entirely unsuitable. For in accordance with this view there would be no place at all in art for the insignificant and ugly. In the definition of a concept which refers to empirical objects an ideal norm is not applicable as an attribute.

3. In the third place we may group together several definitions, in which the *genus proximum* is the same; for they all apprehend art as representation, though they diverge in their statement of what is represented. They designate representation partly as imitation, partly as repetition. Discarding a special accentuation of this distinction, we arrive at the following six definitions:

Art is representation—

(*a*) of nature, or sense-perception—according to Plato, Aristotle and Batteux;

(*b*) of the passions—according to Dubos;

(*c*) of the eternal ideas apprehended through pure contemplation—according to Schopenhauer;

(*d*) of ideas of imagination—according to Riegel;

(*e*) of the beautiful—according to Shaftesbury, Mendelssohn and Schiller;

(*f*) of the infinite, the absolute—according to Schelling and Hegel.

The conception of art as imitation is especially characteristic of antiquity, but obviously imitation was not taken in the strict sense of the word, since poetical description was also included. Batteux, who also says of art that it imitates nature, specifies that a good and selective imitation is meant; while Dubos would speak rather of an image (copy) than of an imitation. Indeed, the narrower meaning of this expression would be valid only for comparatively few works of art, and thus is inappropriate for the *genus proximum*. From the naturalistic standpoint, of course, it is no better. Even though its ideal demand may

be justifiable, there are still, according to its own decree, many things in art which do not satisfy its norm, and we are here in search of only such attributes as may be valid for all given art.

On the other hand, in the assertion that all art is representation lies something manifestly correct. It is based on the observation that all perceptible voluntary actions of living beings mean, express, represent something. This is not only valid for those actions which remain in the bodily sphere, such as language, facial expression and gesture, but also for such as extend their operations into the outer world. The swinging of a bell by the wind expresses in itself nothing, but with a man at the rope it may mean fire. Every voluntary expression of life has an aim and a meaning, and if art is regarded as representation, what is meant is that the work of art has not only been accomplished in the manner of any other event in the sphere of inorganic nature, through causal mechanism, according to necessary laws, but also that it is competent to mean, to express something which in itself is independent of the causal connection of its origin.

Whilst we are able to ascribe to the *genus proximum* of this definition a good and useful meaning, it is not so with the *differentia specifica.* In one form of it we are strangely confronted with the assertion that the infinite or the absolute is represented in art. Without detailed comment this statement can certainly not be understood, and even with comment it forms rather an ideal, an aim, than an unprejudiced determination of the characteristics of art. Similarly the definition by Schopenhauer is based on a metaphysical presupposition, which implies the connection with a peculiar philosophical system. With the non-acceptance of the metaphysics, the general validity of the definition disappears. Much too narrow on the other hand are the limitations (*a*), (*b*) and (*d*). Sense, perception, imagination, passion, all can be represented in art, and therefore none can be used to the exclusion of the others as *differentia specifica.*

The nearest approach to the actual facts is given in definition (*e*). It is true, the conception of the beautiful is by no means

unambiguous. If we understand by it, the pleasant, perhaps even with reference to the direct factor of the æsthetic impression, then that definition is too narrow, for ugliness also obtains in art. But if we make the beautiful to coincide with the æsthetic and thus likewise include the unpleasant, then but a small change is required in order to obtain an approximately satisfactory definition. We need only to speak of *æsthetic representation* in order to describe exactly enough the nature of all art. However, there remains even in this statement a difficulty. By accentuating in the conception of representation the symbolical or sign-nature of the works of art, the fact remains unconsidered that nature must also be regarded from this point of view. By the German word "Einfühlung" has been denoted that process which occurs when we find life, sentiments, forces, expressed or represented in any phenomena whatsoever—not merely in those of art. Every æsthetic impression as such, found or created, is thus capable of suggesting meanings and imparting animation. Therefore the modified definition (*e*) appears too wide, or at least is liable to be misunderstood. In other words the accentuation lies, not in that art represents something, but rather in that it is a product of intentional activity. So we return to the *genus proximum* of the first definition; but the *differentia specifica* can obviously alone be found in the particular properties of the product, *i.e.* in its æsthetic nature. Thus finally we arrive at the definition: *Art is æsthetic product.* But as *genus proximum* we might also employ the conception of the æsthetic impression; though it must be particularly determined through the conception of production. Hence is obtained a definition the converse of the preceding one: *Art is produced æsthetic impression**. That which forms the *genus proximum* in this was *differentia specifica* in the former definition. The conceptional elements, the attributes, are in both definitions the same; they differ only in their logical position. The second definition is preferable since it renders feasible a simple co-ordination of nature and art within the frame of æsthetics.

* I cannot here enter into a more exact determination of the conception of æsthetic impression, and therefore refer the reader to *Vierteljahrschrift für Wissenschaftliche Philosophie*, Vol. xxiii, p. 154.

II.

THE RELATION OF ART TO KINDRED PHENOMENA.

On the basis of the definition developed in the foregoing section, relations are to be assumed, first, to nature, second, to science and to art industry or artisan activity. With the first it has in common the attribute of being æsthetic impression; with the second that of being a creation, a product of human, voluntary action.

1. *The relation of art to nature.* All those æsthetic impressions which are not made or produced belong to the great circle of that which has become, or has naturally arisen, *i.e.* to nature. Thus nature and art divide among themselves the whole realm of the æsthetic with regard to the compass and quantity of that which it presents. Nature certainly exceeds art. That which human hand has brought forth shrinks before the boundless magnitude and abundance of the world as we find it. How powerless appears the painter in comparison with the beaming light which each day brings, filling the widest spaces with innumerable contrasts from bright to dark, with inexhaustible richness of colour-tone, from the deepest to the faintest! How weak appears the musician, even in his grandest compositions, compared with the prodigious gradations of timbre and intensity which the acoustic phenomena in living and inorganic nature present to us at the sea-shore and in the forest, on the mountains and in the valleys, in city and country, above us and below us! What poet has words enough to mirror the various facts of nature, from the inflexible regularity of the inorganic world to man's freest and finest sentiments and emotions! Out of the endless continuity of the temporal course of events, formative art selects one moment; the painter gives up depth and the sculptor colour.

Indeed, from this standpoint art appears only as a limited section of the table of possible aesthetic impressions, one mean patch on the gorgeous garment of the beautiful world. But, as man rises morally above nature, of which, quantitatively considered, he is merely an infinitesimal fraction; as he theoretically encompasses her with formulae, measures, conceptions and laws

—practically governing her; so also can he successfully compete with her as an artist. Art, then, is only at a disadvantage as compared with Nature, when it tries to reach her by imitation—to counterfeit reality. Since such a procedure, demanded injudiciously by Naturalism, must be called aesthetically quite unimportant, even irrelevant, it is quite conceivable that art from a purely æsthetic consideration may surpass nature. If the points in which nature shows herself so rich and great are not essential to the æsthetic effect, but are to a large extent irrelevant or even disturbing, then art may enter into competition with nature and may excel in more than one respect.

(*a*) Art has at its command the *greater purity of æsthetic effect.* It is, according to its nature and purpose, only aesthetic impression, and where there are other additional problems and intentions, as in architecture or art industry, the tendency at least prevails to bring the two into harmony with each other and thus exclude unaesthetic production. In nature, on the other hand, the property of being aesthetic impression is, so to speak, incidental; it is only one moment, and that often not a prominent one. Not in order to please has nature become so and not otherwise, but according to inviolable laws it forms a causal order which only occasionally we adapt or find adapted to the contemplation of aesthetic apprehension. How often we meet with ugliness in nature! And when we speak of beauty it is mostly on the ground of an "Einfühlung" and borrowing, which transforms for us the raw sense impression into a pleasing one, aesthetically applicable. With all kinds of more or less fantastic additions we enrich Nature and thereby render her desirous and capable of satisfying us aesthetically. The predominating part in her is and remains the theoretical and practical meaning—the whole army of counteracting forces which we try to grasp, to understand, and to force into our service. It is only in interludes of quiet reverie that we turn to nature for our contemplative values.

Quite different is art, which owes its existence to the artist, and which he has created purely to satisfy aesthetic wants. In the presence of works of art our thought and will are transformed into contemplation; and this is the proper function of a

work of art. Through the medium of the work perceived we receive the ideas and thoughts of the artist, which do not allow our fancy to have free play, as does nature. The aesthetic in the work of art presents itself to us separated from all disturbing and confusing accessories, from all extraneous meaning and problems. There are no æsthetic adiaphora in it, or at least there should be none. The connection of all constituents is not determined by causal, but by æsthetic points of view. In this the artist has free choice with regard to his subject. Even where he appears to imitate, where he represents a part of nature, every constituent is not of equal value, and he executes, as Batteux expresses it, "a selective imitation."

(*b*) But we may grant to art *the richer æsthetic effect* also in a certain sense. The imagination of the artist is capable of creating that which does not exist in nature, which perhaps even could not exist. The whole realm of sorcery, tradition and fairy tale, of the mythical and the mystical, is open to art, be it poetic or formative. Where in nature are found all those bold and free subjects of ornamentation in which decorative art deals so lavishly? Where in nature arises the artistic yet useful structure which we admire in lofty cathedrals, sumptuous palaces, or monuments? Where, finally, does nature offer us such music as that of our concerts and operas, that harmonious and melodious complication of tones and timbres, which so intimately excites our emotions and so manifoldly inspires our imagination? Many things in nature, as plant and animal forms in ornamentation prove, may have had an influence on the origin of works of art; other things, such as caves and grottoes, may suggest architectonic art. But a real model for art they do not form. Even though all the elements of form and content which are to be found in the productions of the artist may be met with in nature, nevertheless the combinations into which the artist's hand unites them, are characteristic of art; and it is these combinations that determine the total aesthetic impression, thus attaining the peculiar effects which secure to art an advantage over nature. Another source for the greater riches of artistic effect is to be found in that fact which I have else-

where* more particularly discussed under the name of "Æsthetic Justice." This manifests itself in the fact that non-aesthetic values, positive and negative, and even the ugliness of realities, may in artistic representation become objects of pleasure, and thus be transformed into contemplative values. On this uniformity rests a far-reaching advantage of art over nature.

(*c*) There is another point of view which plays an important rôle in art, but is not applicable to nature, namely, *the greater or lesser perfection of the execution.* In nature everything is as it *is*, everything is perfect in its way. In art, on the other hand, the representation of natural objects, of ideas, sentiments, etc., may of course be more or less successful. Here the content, apart from the form which the artist has given to it, is in itself accessible to us, and the artist's intentions can be gnessed. Hence we may compare intention with execution, and also imagine other forms than those selected. This affords an essential contribution to the aesthetic judgment of a work of art, for the execution may please or displease us independently of the subject represented. In this the mere technical means and their applications are of no consequence; such, for instance, as the mechanics of musical instruments, the laws of harmony, the rules of poetic structure, the prescriptions for the preparation of pigments or the production of intensity contrasts. All these belong to a purely technical judgment of the work of art, which can be exercised only by those few who are rendered competent critics through special study and experience. But artistic representations may be judged even apart from technical considerations. We may find a certain musical composition poor in form and void of expression; we may criticise a picture for the harshness of its contrasts; we may think a piece of sculpture stiff; we may censure a poem for its prolixity; and all this without entering into the technical origin of their defects, or the possibility of their remedy. Thus in this direction also art presents to aesthetic judgment a new and varied field of operation.

(*d*) Finally, since art is a product of human voluntary action, *much stricter demands* are made upon it than upon nature. The most improbable, the most undignified, is accepted

*Preussische Jahrbücher, vol. 98, pp. 264 et seq.

of nature, because we are permeated with the conviction that her invariable and inviolable laws have been the cause. The rare, the individual, the abnormal, stand on the same level with regard to necessary conditions as the commonplace, the average, the matter of everyday occurrence. That of which the origin and past are not known compels an acknowledgment of its necessity, quite as much as that of which the course and conditions are sufficiently investigated and made manifest. It is wholly different in art. That which art brings forth is not required to justify itself by recurring also in nature. For every æsthetic impression is pleasant and satisfactory when it is in itself a unity and not dependent for effect upon outside factors. That which is represented in art must therefore of itself appear possible and probable; it must bear in itself the stamp of truth. Art has not been a storehouse of curiosities and abnormalities, but has always been the exponent of typical features. For this same reason accident is prohibited in art. Where the individual, the abnormal, is represented, a circumstantial apparatus of explanatory events must be introduced which makes the peculiarities appear necessary. Thus everything essential in art must be propagated from internal laws. We are dissatisfied when the catastrophe of a novel or drama is not the natural conclusion from the contrivances and developments in the plot, situations and characters, but is brought about by some sudden, natural event or by the accidental interference of third persons. For this reason so-called dramatic music, which acquires the regularity of its progress from its adaptation to a text, has an æsthetically incomplete effect if performed apart from the stage or without the accompanying text.

2. *The relation of art to art industry and science.* The æsthetic difference between nature and art can be reduced throughout to the simple idea that the latter is a product of human volition, an intentionally created æsthetic impression. On the other hand, with regard to the second form of our definition of art, in which the attribute "to be a product" forms the *genus proximum*, the conception of "æsthetic impression" is characteristic of the distinction between art and other products.

(*a*) Art industry, or the product of the artisan, not the artist, which in popular parlance is sometimes accepted as a kind of art, comes under the heading of the useful, and thus serves practical demands only. The ends of art and of art industry are therefore entirely different in principle, and æsthetic satisfaction is not necessarily expected from the artisan's work. But the two are not mutually exclusive. They may combine and form what is called artistic workmanship. In this case the work not only satisfies practical demands but also produces an æsthetic impression. Here, as in architecture, this double destination of the same product of the human hand presents neither difficulty nor contradiction. It is not of essential consequence to the nature of art, whether it appears free and self-dependent, or whether it forms only one aspect of a work, which at the same time is adapted and subordinated to other ends. This distinction is not entirely missing even in the other arts. Thus, for instance, a poetical work may please, and at the same time educate, and satisfy ethical demands. Such by-products may be rarer and less prominent in poetic art, but they play nevertheless a not inconsiderable rôle. Hence a classification of the arts under the double heading of free and unfree formation, as has been proposed and employed by E. Von Hartmann*, is utterly impracticable. It must be always kept in mind that he who criticizes a novel according to the amount of instruction he derives from it, or according to whether good or evil is finally victorious, no more employs an æsthetic standard than he who judges of an artistically carved cabinet according to its cubic contents.

(*b*) Whilst formative art especially stands in a natural relationship to art industry and handicraft, poetry on the other hand is closely related to science and philosophy. There is no doubt that not only can poetical creations have a scientific value, but also scientific works may produce an æsthetic effect. Works such as Freytag's *Bilder aus der deutschen Vergangenheit* and Macaulay's *Essays* give both instruction and pleasure. Such a concurrence of both interests is possible, and even inevitable,

* See his *Æsthetics*, Vol. ii, pp. 586 *et seq.*

since philosophy and science make use, in their representation, of the same material as poetry. Nevertheless their laws and aims remain essentially different. The task of science prescribes for its representations on the one hand obedience to rules of logic, and on the other hand—where empirical facts are depicted—reliable truth in the description. In addition there are certain didactic requirements which are satisfied by suitable grouping of the material, and the selection of comprehensible expression. Hence clearness, precision, exactitude, logical coherence are the demands to be satisfied in scientific works. Doubtless there may be works which comply with these rules without producing a pleasant impression. For this reason there may arise here, as in art industry, the desire to have the aesthetic craving satisfied also, as far as possible, without detriment to the scientific ends. Conversely, it is natural that the work of art may fulfil scientific demands, and inculcate certain scientific truths. But no matter how closely these two points of view may be combined, they remain nevertheless two modes of consideration of the same object, essentially different and distinctly separable.

Hence our definition of art has stood the test in a twofold direction. We may, therefore, unhesitatingly accept it as a basis for a classification of the fine arts. But in this task also we shall proceed by criticism of the many previous attempts to establish a system of art.

III.

CLASSIFICATION OF ART.

The individual kinds, which can be subordinated to the general conception of art are easily enumerated. But even in early times a desire arose to furnish, beyond mere enumeration, a classification, that is, a grouping according to logical points of view. Only in this way a system could be obtained which should characterize the individual fine arts as representatives of certain logical possibilities, and which should reveal the inner reason for their separation. A further effect of such classification would be to enable us to conceive the manifoldness of the

different forms as necessary and at the same time warrant the completeness of the classification.

The division of a generic conception, as accepted, is accomplished by differentiating one attribute of it, the so-called principle of classification. This procedure may be continued with the species thus obtained so that these again are divided into individual forms. Since the first differentiation determines those that follow, it must be kept in mind, in the following discussion, as the gravitation point. The other logical rules, which are necessary for classification, do not need to be specially emphasized.

In the history of æsthetics, five points of view have chiefly been adopted for the primary division of the conception of art: (1) The *senses*, which mediate the perception of the work of art—Batteux, Herder, Hegel, Vischer; (2) The *means of representation* (word, tone, colour, etc.)—Mendelssohn, Sulzer, Kant; (3) The *spacial aud temporal form of the phenomenon*—Köstlin, Schasler, Fechner; (4) The *subjects of representation* (the ideas)—Schopenhauer; (5) The *relation of idea to appearance*—Dubos, Home, Schelling, Hegel.

Within these principles of classification occur naturally many other distinctions. Thus, for instance, Herder makes use not only of the two higher senses which he otherwise exclusively employs,but also of the sense of touch, and he refers to it, the plastic art, as the one which forms entire bodies beautifully. As a curiosity we may mention, that there is even an attempt extant to make use of all five senses for a classification of art. In this attempt architecture is attributed to the sense of touch, sculpture to the sense of taste, painting to the sense of smell, music to the sense of hearing, and poetry to the sense of sight. The name of the fortunate discoverer of these relations is Erhard, and the effusion in which he announces them appeared in 1826. Hegel and Vischer do not carry out consistently their principle of classification—for they assume, besides the fine arts for eye and ear, a fine art also for fancy and imagination, namely poetry.

Within the third principle of division, the decisive part is played by the distinction of rest and motion, of simultaneous and successive phenomena, of spacial and temporal formation.

From the second point of view Mendelssohn and Sulzer have advocated as a first sub-division the well-known separation of fine arts and fine "sciences" (beaux arts—belles lettres), tracing back the former to the natural symbols of that which is to be represented (colour, body, tone), and the latter to artificial or arbitrary symbols (words). Kant on the other hand puts in contra-position the three means of expression, word, gesture and tone, and thus deduces speaking arts, formative arts, and the arts of the play of sentiment.

With regard to the last of the above-mentioned principles, a question arises as to what is to be considered the prototype of the phenomenon. According to Dubos, the emotions and passions are expressed in a work of art, and the arts are classified according to the immediateness and vivacity with which they reproduce their subjects. Music, therefore, stands first, painting takes a middle position, and the weakest and most indirect is the representation of the passions in poetry. Home, on the other hand, makes the relation of art to nature the criterion. Accordingly he distinguishes an art which merely beautifies nature (horticulture), then imitative arts (painting and sculpture), and finally creative arts, tied to no natural model (architecture, poetry and music). Schelling proposes a real and an ideal series of arts according as the reality of the phenomenon or the idea prevails; among the former he reckons music, painting, and sculpture, and among the latter lyric, epic, and dramatic poetry. Hegel, finally, finds a preponderance of phenomenon over idea in symbolic art (architecture), an equilibrium of the two in classical art (sculpture), and a preponderance of idea over phenomenon in romantic art (music, painting and poetry).

We may prepare the way for our criticism of these attempts at classification by simplifying the preliminary system. First, it is clear that among the attributes comprehended in the conception of art, only that of "æsthetic impression" has undergone a differentiation. Not a single one of the above-mentioned principles of classification goes back to the conception of product. Now, we distinguish in the æsthetic impression two factors, the direct and the associative,* of which the former points

*Compare my essay cited above (in *Vierteljahrschrift für wissensch. Philos.* xxiii, 154).

to the sensational side of the phenomenon, and the latter to the associated presentations. Accordingly the three first principles of classification may be grouped under the head of the direct factor, whilst the fourth corresponds to the associative factor, and the fifth expresses the relation between the two. These three principles not only simplify the original scheme, but give at the same time an insight into the possibilities at our disposal. For the conception of product does not furnish a classification according to æsthetic, but according to technical, or other non-æsthetic points of view; and the factors above set forth give a complete primary differentiation of the conception of æsthetic product. Consequently the three new principles of division present an exhaustive list of the possibilities of differentiation which are to be considered with respect to the conception of art in general. Turning now to criticism, we may begin with the conviction that we have before us all æsthetic principles of classification which reasonably could be taken into account.

(*a*) First, it is clear that the associative factor cannot form the basis of a useful classification of art. For in the first place the manifoldness of the presentations, of the subjects of representation, is so great, even in one and the same work of art, that the latter may have different meanings for different individuals, and thus be variously assigned to one or another kind of art. A "still-life" picture may present as its subject for A a sentiment, for B simply a combination of objects, for C general ideas. In hearing operatic music, one who is acquainted with the whole work may picture to himself the scenes and actions concerned, whilst another who is not acquainted with the opera, if he fancy anything scenic at all, will not go beyond vague images. Is by this difference in the associative factor a difference introduced into the work of art itself? Further, the objects capable of representation by one form of art are so various, that if the principle of classification is to be sought in them, they themselves must needs be divided into different classes. In painting, we meet with landscapes, animals, domestic events, historic scenes, and so on; in poetry we have to cope, so to speak, with everything which can be experienced, thought, or imagined. In spite of these considerable differences

in the associative factor, poetry and painting, according to g
eral agreement, remain undivided forms of art. Thirdly, if
is allowed to find the principle of classification in the subject
representation, different arts, in so far as they deal with
same subject, would merge into a common class. From
point of view landscape-painting and the poetical descriptio
scenery, the historical picture and the plastic group represent
a historical event, passionate music and a lively dance, woul
grouped together, in *one* conception. On this princi
therefore, those which naturally belong together are torn ap
and those which should be separated are combined, quite a
trarily. Schopenhauer, who alone has attempted this classi
tion, does not shrink from co-ordinating architecture and hyd
lics, and he gives to both the lowest rank in art, because t
represent ideas of the lowest objectivity of the will, viz. grav
hardness, mobility and so on. Similarly, horticulture and la
scape painting, animal painting and animal sculpture are pla
side by side. It must be regarded as an inconsistency
poetry is not mentioned. Indeed we cannot wonder that m
cians are so enthusiastic for Schopenhauer's philosophy, for t
find in his curious system their own art placed at the sum
because it essays to picture will itself, the reality of the wo
No such enthusiasm has been manifested by architects. If
did not know that Schopenhauer according to his mode of th
ing belongs to the same school of philosophy as Hegel
Schelling, whom he has so unjustly abused, one might recog
it from his classification of art.

(*b*) The third principle, the relation between the direct
the associative factor, phenomenon and idea, has this decided
vantage over the second, that it emancipates itself from
qualitative manifoldness of the associative factor. But e
here some objection arises. For, here also may occur consi
able individual differences with regard to the same work of
For one the associative, for another the direct factor may
vail. Does this, then, necessitate an assignment to diffe
types of art? And secondly, works belonging to the same
may be very differently placed with regard to their relat
In music, for instance, Mozart has laid more stress on beaut

form, Wagner, on the other hand, on expression. Consequently music should not be called simply a romantic art. We find here essentially the same difficulties as with the selection of the associative factor for principle of classification, and they obviously arise just from the participation of this most individual, most subjective and least comprehensible moment.

(*c*) It follows from what has preceded that only the direct factor can induce a differentiation of the conception of art. Indeed it is the only applicable principle of classification, because it alone presents the objective mediation between the artist and the appreciator, viz. those contents of the work of art which are approximately equal for everybody. Individual taste here finds a limit set to it. The direct factor is the basis and starting-point for all presentative activity, and a ground of agreement for all differences of opinion. This may be the reason why the direct factor has comparatively often, in our first scheme in three different forms, played the decisive rôle for the classification.

(α) Among these three forms the justification of the first—the division according to the senses—must be acknowledged. For certainly there are arts which appeal exclusively to the sense of sight, and others which appeal just as exclusively to the sense of hearing. But it is utterly false to include, with Herder, the sense of touch. The function of the sense of touch may for blind people be æsthetic. Smoothness and symmetry in the space configuration have, through the sense of touch, a pleasant effect on their mind. But from this to an art completely confined to this sense alone is a long step, and under no circumstances should sculpture be regarded as such an art. The assumption of Herder rests on the theory that only the sense of touch furnishes us with a knowledge of the third dimension of space, and thus of solids. It seems that the surprising experiences, which became known at that time, with people born blind, who had undergone successful operation, had cast a too favourable light on the services of the sense of touch.

It is equally inadmissible to place, with Hegel and Vischer, imagination on a par with eye and ear as a receptive faculty, or, so to speak, an inner sense. For poetry, on account of which

this third faculty is introduced, is not directly, but only indirectly, capable of acting upon imagination, viz. through the mediation of one of the senses. But neither do the other arts lack the stimulation of imagination. It is brought into play also in viewing pictures or the products of plastic art. Consequently to imagination a peculiar function for the reception of poetical effect alone cannot be assigned. But a supplementary class of arts, as we may briefly call them, is required; for there are arts which have an effect on eye and ear at the same time. To these belong drama and opera. Thus we have to add to these two forms of art, a third one, viz. optic-acoustic art.

(β) The second point of view which comes under the conception of the direct factor, that of phenomena of space and time, of the simultaneous and successive, or of rest and motion, could only then properly be combined with the first, if it would admit the introduction of a further differentiation. But this is impossible in the case of acoustic arts. Every art addressed to the sense of hearing contains necessarily the attribute of the successive, thus excluding a purely simultaneous effect. The same is naturally the case in the optic-acoustic arts. Conversely, one may say that succession occurs also in optical arts, but that it has no distinct significance. Thus for instance mimicry, which presents to the eye a succession of gestures, can be regarded as an independent art. But if we were to adopt this standpoint, viz. that of time and space relation, for the chief division, it would be found that for the simple and concrete classification according to the senses we had substituted an abstract principle which it might be impossible to apply throughout without contradiction. Even less suitable appears to me the contraposition of rest and movement. If thereby is understood, according to ordinary usage, a pair of conceptions for which the moment of the spacial process is essential, music and poetry could not be classified at all. One must therefore assign to each a more abstract significance, namely, that of the simultaneous and successive, or that of the permanent and variable, in order to make them universally applicable. But this classification lands us in the same difficulties as have been discussed above.

(γ) On the other hand, in the secondary division, the third point of view, that of the means of representation, can be very well employed, as a natural differentiation of sense impressions. What differentiates painting from sculpture, in the optic, and music from poetry in the acoustic arts, is precisely that which separates, respectively, surfaces from bodies and tones from words, as individual, optic and acoustic contents. Here also occurs the difference between the simple and the mixed, and correspondingly the difference between indivisible and aggregate arts. Thus, every form of art within the third division of each of the three chief groups deals with a combination of the means of expression which serve the other two. We obtain, therefore, the following system :

A. Optic arts (appealing to the sense of sight) :
   I. Surface arts, producing works on surfaces :
      a, in uncoloured or monochrome execution : Drawing ;
      b, in polychrome execution : Painting.
   II. Solid arts, producing plastic works :
      a, in semi-solid form : Relief and Intaglio ;
      b, in completely solid form : Sculpture.
   III. Aggregate arts ; combining surface and plastic effects:
      a, Tectonic ;
      b, Architecture.

B. Acoustic arts, (appealing to the sense of hearing) :
   I. Art of tones : Music ;
   II. Art of words : Poetry ;
   III. Aggregate art of tones and words : vocal and melo-dramatic music.

C. Optic-acoustic arts (appealing to both the higher senses) :
   I. Art of gestures and tones : Choreographic art ;
   II. Art of gestures, words and scenery : Drama ;
   III. Art of gestures, words, tones and scenery : Opera.

We may add to this scheme a few observations. Under the heading " Art of Drawing " we include, as is not unusual now-adays, engraving and etching, xylography, etc., *i.e.* all the arts, no matter how different technically, the products of which with regard to the direct factor consist for the observer in an uncol-

oured or monochromatically treated surface. It may perhaps seem strange that we include under painting the art of making Gobelins and tapestry too. But from an æsthetical standpoint, that is, with reference to the æsthetic impression, the similarity of impression with regard to the direct factor must be decisive for this classification. It is by no means intended to preclude a further differentiation of arts. On the contrary, just where æsthetics ends comes in the dividing activity, the characteristic of production, the technical procedure, and submits the conceptions of the arts of drawing, painting, etc., to further analysis.

That tectonic art and architecture employ and represent both surfaces and solid bodies, treating the former in the manner of surface art, and the latter in the manner of solid art, but at the same time producing out of both a separate unity, scarcely needs explanation. Anticipating, however, a misunderstanding or perhaps even an utterly incorrect apprehension of what is meant by "aggregate arts," we may here emphasize the fact that not surface and solid arts are combined in architecture, but that the means of expression of the two kinds are made to serve a new form of art, which is a unity in itself, and not a combination of other arts. Objection may be taken to including poetry among acoustic arts. Poetry may be read, and thus acts only on the eye. But the direct factor in poetical compositions is never the written or printed text, but the audible word. Rhyme and rhythm play no part for the mere reader. Poetry produces its full æsthetic effect only in audible recitation. The written or printed text represents here, as in music, only a direction, or a system of representative symbols, for the executant, and does not possess an independent or original significance for the æsthetic impression.

For the combination of words and tones in a new aggregate art there is no general term. We include in it not only singing, *i.e.* vocal music, but also "programme music," in so far as it aims at an organic combination of word and tone, and, finally, recitation accompanied by music. In the two latter cases, the interest usually is concentrated more or less on one or the

other side of the combination, thus not permitting a real and complete union as we have it in singing.

In the third group the conception of aggregate art attains decided significance. Consequently, music and poetry can no longer be spoken of as independent forms of art, nor can architecture and formative art, with regard to stage scenery. The means of representation, independently treated and combined in these single arts, form rather the constituents of a comprehensive whole, in which the direct factor assumes a considerably more manifold aspect. It was the mistake of Richard Wagner to see in the totality of the opera merely a fusion of the individual arts, and thus he has built his theory of the opera upon an incorrect basis.

The position of choreographic art in this class is doubtful. For the acoustic impression furnishes in ordinary dancing merely a reliable marking of the rhythm, without claiming the significance of an independent, æsthetic factor. But in the play of motion which we call dancing we can scarcely look for real art. Pantomime and ballet on the other hand appear always in combination with a musical accompaniment to which they belong, and to the evolutions of which they correspond. Only in these two have we the real representatives of choreographic art. Since the rhythm of motion which is essential to them scarcely exists for the mere visual observation, the acoustic supplement is indispensable for the spectator.

EXPERIMENTS ON THE AESTHETIC OF LIGHT AND COLOUR

SECOND ARTICLE

SPECTRALLY PURE COLOURS IN BINARY COMBINATIONS

BY

EMMA S. BAKER, B.A.

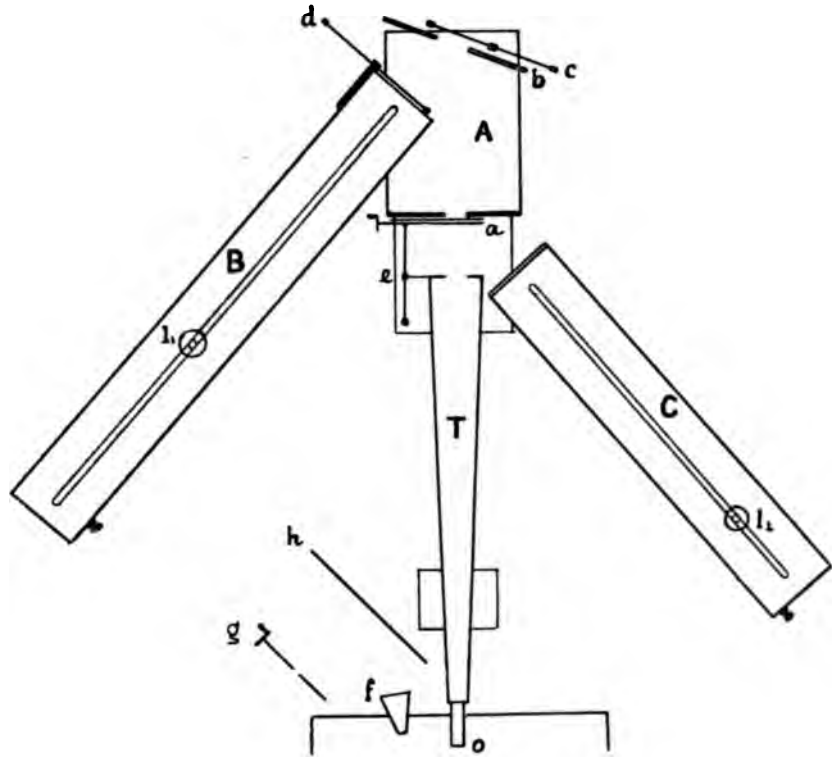


PLATE A

SPECTRALLY PURE COLOURS IN BINARY COMBINATIONS

In the fourth number of the Psychological Series of University of Toronto Studies[1] was published an article containing the results of experiments on the æsthetic value of colour combinations. The colours used in those experiments were pigment colours, and the surfaces were the same in shape and of equal size. In view of the importance of the relative proportions of the surfaces, it was thought desirable to conduct a second series of experiments, in which it might be possible to vary the size of the surface. This phase of the problem was investigated during the years 1899-1900 and 1900-01, in room 16 of the Psychological Laboratory[2].

The apparatus and method employed were entirely different from those used in the former experiments. The apparatus was that described by Dr. W. B. Lane, in an article entitled "Space Threshold of Colours and its Dependence upon Contrast," published in No. 1 of the Psychological Series of University of Toronto Studies. As Dr. Lane's article contained an illustration and a detailed explanation of the apparatus, we shall confine ourselves here to a short description of it, particularizing the changes which our experiments necessitated, and illustrated by a schematic representation (Plate A) which gives a view of the apparatus from above.

In the plate, A is the central table; upon the front edge is erected the upright with the micrometer diaphragm *a*, of which Figure 2 in Dr. Lane's article gives an illustration. At the other end of this table, in a somewhat slanting position, there is another upright *b*, through which is visible one of the coloured pigments arranged on a movable disc *c* behind it. The pigment is illuminated by the electric light *lr* adjustable to various distances in box B. The rays of this light have to pass through one of the combinations of gelatines which are arranged in the form of a revolving wheel *d* at the front of the box. The com-

[1] Vol. I., p. 203.

[2] See plan of the Laboratory in Vol. I.

binations of absorbing media are selected in such a way that light which has passed through one of them and is then reflected from the corresponding part of c^1 will be confined to a very limited part of the spectrum, thus furnishing light just as pure as if a certain region of the spectrum itself had been taken, but not limited in intensity and space extension. This light is then seen through the observation tube T, and through the aperture of the diaphragm *a*, whilst the opaque parts of the latter are covered with another pigment paper illuminated in an analogous manner by means of *l2* in box C.

At the end of box C is inserted a gelatine preparation as required by the ground colour. Since the ground colour remains constant during a whole series of experiments there is no need for the gelatine preparations to be arranged in the form of a disc. They are identically the same as those for the other box but they have the form of squares of the same size as the opening of the box. The observation tube T is attached to the moving part of the diaphragm *a* by a lever arrangement *e* in such a manner that its end moves with half speed. This keeps the middle part of the diaphragm always in the centre of the field. At the ocular end of this tube *o* a large screen shuts off the eye of the observer from all other parts of the apparatus. The eye-piece *f*, the graduated slit *g*, and the screen *h*, render it possible to compare the light seen through the tube with real spectral light generated by a lantern and spectral apparatus in an adjoining room (the first annex of Room 16). Through the observing tube can now be seen the two surfaces, the ground colour on the diaphragm, illuminated by *l2*, and through the opening of the diaphragm the colour to be combined with the ground colour, illuminated by *l1*. There were twelve colours in all which could be changed by a revolution of discs *c* and *d*.

The intensity differences were eliminated in the following way: The distances of lights *l1* and *l2* were gradually changed until the two surfaces appeared of equal brightness.[2] The correct distances of the lights having been found, they were marked on the sliding scales of boxes B and C. The ground colour, which

[1] See also Dr. Lane's article.

[2] See also Dr. Lane's article, pp. 23-24.

was constant through a series of trials, was given, by the position of *l2*, the intensity which the same colour had as seen through the diaphragm. It is easily possible by adjusting the lamps to arrange the intensities in such a manner that the ground colour and the transmitted colour form one uniform surface. It may be remarked that we succeeded in getting the two colours to look so exactly alike, that, although there is a distance of about two feet between the two surfaces, the observer at the end of the tube could not possibly detect the slightest deviation from a uniformly coloured surface, no matter what was the aperture of the diaphragm revealing the transmitted colour.[1] And, indeed, before each series of trials this impossibility of distinguishing the surfaces was made the criterion for the correctness of the intensity of the ground colour.

We next come to the method of procedure. The room was darkened and the observer placed himself at the end of tube T where he saw first the ground colour only, illuminated as described. Then by turning the micrometer handle there was made to appear in the centre one of the other twelve colours. This colour appeared first as a little spot. As it increased and rose above the characteristic space threshold[2] the observer stated whether the combination was pleasant, and whether it became more or less pleasant with the change in the comparative proportions of the two components; for as the transmitted colour increased the ground colour decreased until finally only a small border of it was left. The observer, who had now seen all the possible relations in size of the two components, was asked to decide if the combination on the whole was very pleasant, pleasant, indifferent, or unpleasant. This was not

[1] Miss Baker calls the qualities obtained by the above described method "spectrally pure," meaning thereby that a limited region of the spectrum is selected without admixture of light from other regions. I regard this as the only correct way of using the term "spectrally pure," which admits of degrees. If by a "pure" spectrum is understood a spectrum which has at every point light of *one* wave-length only, then a "pure" spectrum is impossible, as I have shown elsewhere. And even if such a spectrum could be obtained it would be absolutely impossible to produce one of its colour-qualities homogeneously on a surface. Much of what has hitherto been said and is generally accepted with reference to the "purity of spectral colours" owes its prestige to errors of thought, concealed behind abstruse terms and complicated formulas.—*A. Kirschmann.*

[2] See Dr. Lane's article.

always an easy judgment to make, for in some combinations the affective character varies very much even to the extent of being unpleasant at one comparative proportion and very pleasant at another. This estimation had no direct bearing on the real problem for which this investigation was undertaken, namely that of the influence of the relative size; the judgment was taken to see if under entirely different conditions the results of our former experiments would be corroborated. By a comparison of curves 1-12 with curves I-XXIV of our former article to which attention will be more fully called further on, it will be seen that the results of the two series of experiments do not essentially differ.

As we reversed the proceeding, the transmitted colour becoming gradually less and less, the observer stated where the combination was most pleasant or, if unpleasant, where it was comparatively most pleasant. Each full turn of the micrometer handle changes the mutual space relations between the diameters of the two colours by the twentieth of an inch. In doubtful cases to secure a definite decision the procedure was repeated, if necessary, several times. In this way all the eleven colours were treated successively with the same ground colour. A whole series of trials was taken at one sitting. The same procedure was repeated with each of the colours as ground colour. A spectroscopical analysis of the colours used will be found on the following page.

There were in all $12 \times 11 = 132$ combinations. In each series of trials there were 25 observations, giving $132 \times 25 = 3300$ judgments of very pleasant, pleasant, indifferent or unpleasant. Of these twenty-five observations, eleven were made by regular observers who took the whole series, and in several cases repeated the experiments. Many took about half the series, and in each individual series there were a few casual observers. It is only fitting here to acknowledge our great obligations to all these ladies and gentlemen, who, often at a great inconvenience to themselves, were so faithful in their appointments and manifested such an interest in the problem.

For the phase of the problem which refers to the size of the components there were 3300 complete transitions from the

Spectroscopical Analysis of the Colours Used.

Name of Colour.	With Narrow Slit.		With Wide Slit.	
	Visible part of Spectrum in $\mu\mu$	Region of greatest intensity in $\mu\mu$	Visible part of Spectrum in $\mu\mu$	Region of Greatest intensity in $\mu\mu$
Red.	665(?)—592.5	635—610	672.5(?)—580	657.5—615
Orange-Red.	622.5—582.5	612.5—592.5	635—580	622.5—592.5
Orange.	607.5—552.5	585—562.5	622.5—547.5	607.5—562.5
Orange-Yellow.	587.5—547.5	562.5—557.5	617.5—537.5	602.5—555
Yellow.	580—512.5	562.5—535	615—492.5	587.5—555
Yellow-Green.	565—497.5	535—525	580—480	555—530
Green.	542.5—492.5	530—507.5	570—480	537.5—517.5
Green-Blue.	525—472.5	512.5—495	550—447.5	525—502.5
Blue.	510—460	492.5—475	535—445	512.5—492.5
Violet.	482.5—432.5	470—462.5	497.5—430	475—455
Violet-Purple.	687.5—665 485—440	462.5—455	700—665 487.5—430	470—452.5
Purple.	680—645 480—430		680—635 497.5—430	475—460

smallest to the largest. For each of these transitions which were continuous we chose fifty stations for which we give the values in our tables and curves. Tables I, II, III and IV represent the tabulated results of all these experiments from the former point of view. These tables are constructed in an analogous manner to those of our former experiments. Tables I and II represent the "pleasant" combinations, and III and IV the "very pleasant." It must not be forgotten that we deal here as in our first article with highly saturated colours. Colours of high saturation are in themselves almost without exception agreeable, but their combinations, if not associated with particular objects, are neither pleasant nor unpleasant in the same degree as combinations in which one of the components is of lesser saturation. The present inquiry is therefore only one step in the desired direction. The investigation of the æsthetic value of binary and other combinations of less saturated colours, which will bear much more on the practical than does the subject of this discussion, is to follow.

RESULTS OF EXPERIMENTS.

In Table I the initial letters at the top in horizontal order represent the ground colours, red, orange-red, etc. Those at the left in vertical order represent the transmitted colours, the colours that were combined with the ground colour. Thus when red was the ground colour, it was chosen three times with orange-red and seven times with orange as a pleasant combination, as can be seen from Table I. Table III is analogous to Table I, representing the very pleasant combinations. In Tables I and III each of the sums of the vertical columns represents the total number of judgments of "pleasant" and "very pleasant" respectively when the colour at the head of the column was the ground colour, whereas the sums of the horizontal series give the total when the colour at the opposite end of the line (as transmitted colour) was combined with each of the others respectively. The number at the lower right-hand corner of each table gives the totality of the combinations selected. In Tables II and IV each of the numbers at the diagonal indicates the sum total of all the judgments for the

Table I.—Pleasant Combinations

	R.	O.R.	O.	O.Y.	Y.	Y.G.	G.	G.B.	B.	V.	V.P.	P.	
R.		5	18	14	18	24	25	19	16	18	14	11	182
O. R.	3		12	8	16	23	24	21	19	16	11	10	163
O.	7	5		4	9	15	20	23	22	18	11	12	146
O. Y.	10	5	1		9	16	17	16	20	16	11	12	133
Y.	10	10	10	8		17	17	18	19	21	21	19	170
Y. G.	21	16	12	10	11		5	9	7	15	21	17	144
G.	22	20	16	19	18	6		6	4	13	16	14	154
G. B.	22	21	18	17	20	7	3		1	7	13	18	147
B.	23	18	18	17	20	8	3	2		5	7	14	135
V.	19	16	17	16	18	18	15	6	6		3	11	145
V. P.	16	14	21	17	19	16	17	11	8	9		6	154
P.	10	12	19	18	20	23	23	20	15	19	12		191
	163	142	162	148	178	173	169	151	137	157	140	144	1864

TABLE II.—PLEASANT COMBINATIONS.

R.	O.R.	O.	O.Y.	Y.	Y.G.	G.	G.B.	B.	V.	V.P.	P.	
345	8	25	24	28	45	47	41	39	37	30	21	R.
	305	17	13	26	39	44	42	37	32	25	22	O.R.
		308	5	19	27	36	41	40	35	32	31	O.
			281	17	26	36	33	37	32	28	30	O.Y.
				348	28	35	38	39	39	40	39	Y.
					317	11	16	15	33	37	40	Y.G.
						323	9	7	28	33	37	G.
							298	3	13	24	38	G.B.
								272	11	15	29	B.
									302	12	30	V.
										294	18	V.P.
											335	P.

3728 = 2 × 1864.

TABLE III.—VERY PLEASANT COMBINATIONS.

	R.	O.R.	O.	O.Y.	Y.	Y.G.	G.	G.B.	B.	V.	V.P.	P.	
R.		2	5	5	11	12	18	14	9	6	5	7	94
O.R.	0		4	3	11	11	16	11	10	6	6	4	82
O.	2	2		0	3	3	6	9	6	6	4	3	44
O.Y.	1	1	1		1	6	4	6	3	6	2	5	36
Y.	4	3	3	2		5	6	9	10	12	12	7	73
Y.G.	6	6	5	7	5		1	4	4	5	1	6	50
G.	10	7	6	5	6	2		2	0	4	3	3	48
G.B.	6	8	4	4	8	0	0		0	1	2	5	38
B.	6	8	4	5	9	0	0	0		1	2	4	39
V.	5	3	8	6	10	4	4	2	2		0	3	47
V.P.	2	0	5	4	9	7	5	3	2	2		1	40
P.	3	1	5	10	15	12	13	8	8	9	4		88
	45	41	50	51	88	62	73	68	54	58	41	48	679

TABLE IV.—VERY PLEASANT COMBINATIONS.

R.	O.R.	O.	O.Y.	Y.	Y.G.	G.	G.B.	B.	V.	V.P.	P.	
139	2	7	6	15	18	28	20	15	11	7	10	R.
	123	6	4	14	17	23	19	18	9	6	5	O.R.
		94	1	6	8	12	13	10	14	9	8	O.
			87	3	13	9	10	8	12	6	15	O.Y.
				161	10	12	17	19	22	21	22	Y.
					112	3	4	4	9	8	18	Y.G.
						121	2	0	8	8	16	G.
							106	0	3	5	13	G.B.
								93	3	4	12	B.
									105	2	12	V.
										81	5	V.P.
											136	P.

1358 = 2 × 679.

colour at the head of the column and also at the right-hand end of the horizontal; for example, 345 in Table II indicates the sum total for all the judgments for the colour red.

In order that these results may be compared with those of the former experiments, they have likewise been expressed in curves with the series of colours in spectral order as the abscissa line and the frequency of their selection as ordinates. These curves are designated by Arabic numerals, and the letters *a b c*, in addition to the name of the respective colours to whose combinations the curves respectively refer. The lower curve in each case represents the "very pleasant" combination; the upper, the "pleasant" including the "very pleasant."

Curve 1 (*a*, *b*, and *c*) represents the results of all the combinations in which the colour red took part, Curve 2, those in which the colour orange-red took part, Curve 3, orange, etc.; *a* in each case represents the results when the colour indicated below was the ground colour, and corresponds thus to the vertical columns in Tables I and III; *b* on the other hand stands for the results when the colour indicated below, as transmitted colour, was combined with all the others, thus corresponding to the horizontal columns of Tables I and III. The height of the ordinates is taken from Tables I and III. Thus in Curve 1 (*a*), where red was the ground colour, it was chosen three times with orange-red, seven times with orange as a pleasant combination; when red was the transmitted colour (*b*) it was chosen five times with orange-red and eighteen times with orange as a pleasant combination. Finally *c* is the combination of the two, thus corresponding to the results in Tables II and IV.

In these experiments, as in our former ones, each colour appeared twice; in this case once as the ground colour and once as the transmitted colour. When the surfaces were of equal shape and size and were placed side by side as in the former experiments the results could unhesitatingly be combined; but in our present experiments, as can easily be seen, this could not be done, for when the colour appears as the ground colour it forms a border, whereas when it appears as the transmitted colour it is in the centre and the effect is quite different. Comparison of *a* and *b*

in this series of curves will show this difference. Consequently the *c*-curves are of relatively much less significance.

Curve 13 is a combination of all the curves. *A* represents that each of the colours below as ground colour was combined with all the others, and is therefore formed from the sums of the horizontal columns of Tables I and III respectively. *B* indicates that each of the colours below as transmitted colour was combined with all the others, and is therefore formed from the sums of the vertical columns of Tables I and III respectively. *C* represents a combination of *a* and *b* and is formed from Tables II and IV respectively, the ordinates corresponding to the sums which stand at the hypotenuse of the triangle.

In comparing these curves with those of the former experiments, we find the same general characteristics in spite of the great difference in the conditions. It must be noticed, however, that these characteristics cannot here be expected to be as marked as in the former case, since we now have only half the number of colours. In all those curves for orange and yellow we find the same broad, plateau-like shape. We find, too, that like those with which we are comparing them, these curves do not reach to so great a height as those expressing the other qualities. In many of the other curves we can trace a striking similarity with the curves of the former series, but it must not be forgotten that it would never be possible to trace all the prominences in these, on account of the smaller number of qualities, nor that the changed space conditions alone would prevent a complete analogy.

It is interesting to notice the difference in the maximum when the colour is the ground colour (*a*) and when it is the transmitted colour (*b*). In the curves for the "pleasant" in no case do these coincide except in that of green, where the maximum in both cases is as red. In the "most pleasant," however, there is a coincidence in the cases of red, green, blue, and violet-purple.

In this series of experiments as in the former it was not known until after the experiments were completed which of the colours used, if any, were complementary. It will be remembered that, in order to have each colour as free as possible from

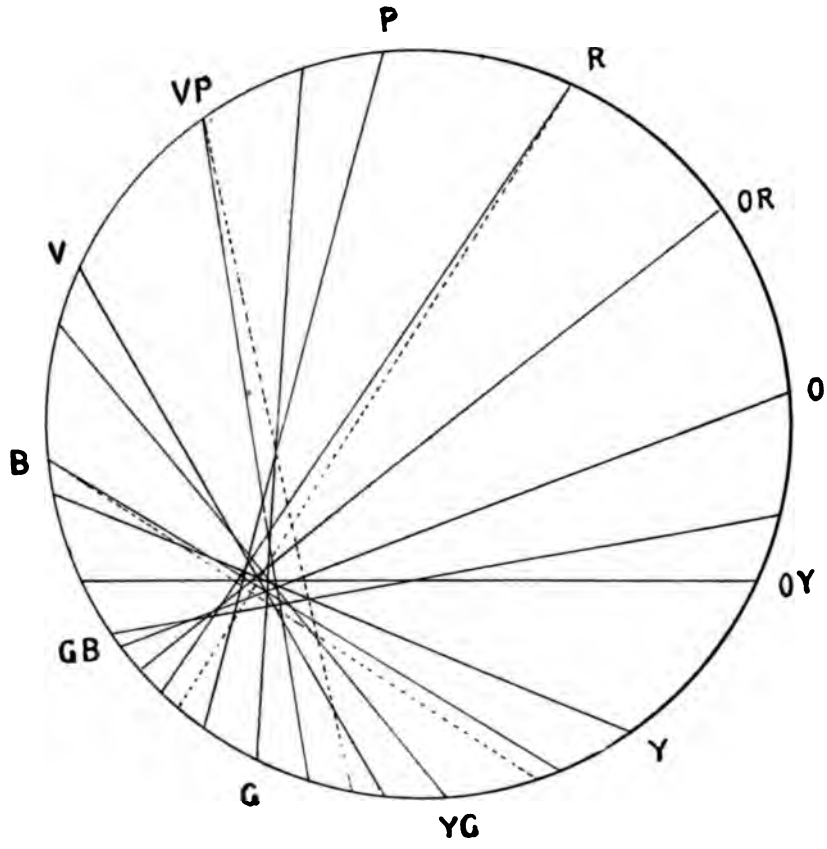


PLATE B

admixture with other colour tones, the colours used were obtained by illuminating pigment papers with light which had undergone a strong selective absorption. This made it impossible to get the complementary relation of these colours in the ordinary way, *i.e.*, by making colour equations as was done in the former experiments.[1] We have to thank Mr. A. H. Abbott, first assistant in the Psychological Laboratory, for the suggestion of the following method which was adopted. The upright blackened board, to which was attached the metal diaphragm, was replaced by another in which an opening of two and a half inches was made, and with which all other space relations were preserved. Now, by looking through the observing tube the transmitted colour can be seen as before. To the back of this upright board was attached a small electric motor to operate a rotation apparatus in front of the board. This latter makes it possible to rotate, as a kind of episcotister, sectors of any colour whose angular value could be varied between the limit of 10 and 360 degrees, the measurement to be obtained from a gradation at the periphery. When rotating we see the mixture of the colour of the rotating sectors and that transmitted through the aperture. Both colours are in the same illumination as in our trials; and if two of our colours were actually complementary we should, by varying the sectors of the rotating part (ground colour) till we reach colourless light as a result, be able to establish a complete colour equation. Unfortunately it was found that there was not a single pair of complementaries among our twelve colours, and since with our method it was not possible to mix more than two colours, we could only make out that the complementary of a certain colour was between two others and nearer to one than the other.

The complementary relation of the different colours as ascertained from the judgments of two observers will be found by examining the accompanying plate (B), which is made according to Table V. The fully drawn lines represent the results of observer K. Where observer A differed noticeably his decisions are indicated by dotted lines.

[1]See University of Toronto Studies, Psych. Ser., Vol. I, p. 241 (No. IV, p. 65.)

TABLE V.

Ground-colour :	Complementary Colour : Observer K.	Observer A.
Red	Between Green-blue and Green, nearer Green-blue.	Between Green-blue and Green, about midway.
Orange-Red	" Green-blue and Green, much nearer Green-blue.	" Green-blue and Green, much nearer Green-blue.
Orange	" Green-blue and Green, almost at Green-blue.	" Green-blue and Green, very close to Green-blue.
Orange-yellow	" Blue and Green-blue, nearer Green-blue.	" Blue and Green-blue, nearer Green-blue.
Yellow	" Blue and Green-blue, nearer Blue.	" Blue and Green-blue, nearer Blue.
Yellow-green	" Violet and Blue, nearer Violet.	" Violet and Blue, nearer Violet.
Green	" Purple and Violet-purple, a little nearer Purple.	" Purple and Violet-purple, somewhat nearer Purple.
Green-blue	" Orange-yellow and Orange, nearer Orange-yellow.	" Orange-yellow and Orange, nearer Orange-yellow.
Blue*	" Yellow-Green and Yellow, about midway.	" Yellow-green and Yellow, slightly nearer Yellow-green.
Violet	" Green and Yellow-green, much nearer Yellow-green.	" Green and Yellow-green, much nearer Yellow-green.
Violet-purple	" Green and Yellow-green, much nearer Green.	" Green and Yellow-green, about midway.
Purple	" Green-blue and Green, nearer Green.	" Green-blue and Green, nearer Green.

*It must be noticed from the spectroscopical analysis that our green-blue is by far more blue than green and that our blue is strongly on the violetish side somewhat like ultramarine in pigment colours.

TABLE VI.—Maximal Points of "Pleasant."

Colour.	a. Colour.	a. Number of Judgments.	b. Colour.	b. Number of Judgments.	c Colour.	c Number of Judgments.
Red.	B.	23	G.	25	G.	47
Orange-red.	G.-B.	21	G.	24	G.	44
Orange.	V.-P.	21	G.-B	23	G.-B.	41
Orange-yellow.	G.	19	B	20	G.&B.	36
Yellow.	G.-B.,B &P.	20	V.&V.-P.	21	V.P.	40
Yellow-green	R.	24	V.-P.&R.	21	R.	45
Green.	R.	25	R.	22	R.	47
Green-blue.	O.	23	R.	22	O.	42
Blue.	O.	22	R.	23	O.	40
Violet.	Y.	21	R.	19	Y.	39
Violet-purple.	Y.&Y.-G.	21	O.	21	Y.	40
Purple.	Y.	19	Y.-G.&.G.	23	Y-G.	40

TABLE VII.—Maximal Points of "Most Pleasant."

Colour.	a. Colour.	a. Number of Judgments.	b. Colour.	b. Number of Judgments.	c. Colour.	c. Number of Judgments.
Red.	G.	10	G.	18	G.	28
Orange-red.	G.-B.&B.	8	G.	16	G.	23
Orange.	V.	8	G.-B.	9	V.	14
Orange-yellow.	P.	10	Y.G.,G.-B.&V.	6	P.	15
Yellow.	P.	15	V.&V.-P.	12	V.&P.	22
Yellow-green.	P.&R.	12	O.Y.	7	P.&R.	18
Green.	R.	18	R.	10	R.	28
Green-blue.	R.	14	O.-R&Y.	8	R.	20
Blue.	O.-R.&Y.	10	Y.	9	O.-R.(18)Y.	19
Violet.	Y.	12	Y.	10	Y.	22
Violet-purple.	Y.	12	Y.	9	Y.	21
Purple.	R.&Y.	7	Y.	15	Y.	22

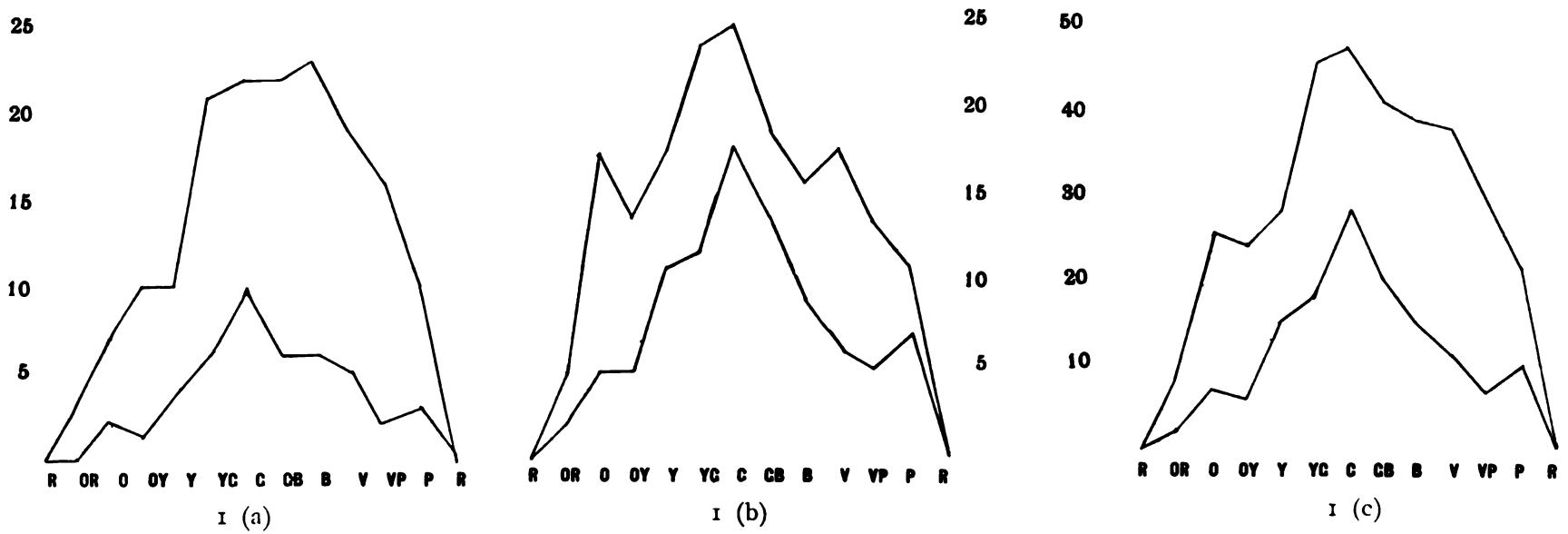
In Tables VI and VII the reader will find the maxima tabulated. By consulting Table V the complementary relations can be easily ascertained.

In considering the relation in which our results stand to the theory that the most agreeable combinations are found with complementary colours, we shall classify them into groups as we did with the results of the former experiments. First, we find only a very few cases where we could say that the maximum might possibly coincide with the complementary colour. Thus, for instance, for orange-red whose complementary is between green-blue and green, but nearer to green-blue, we find the maximum for Curve *a*, "pleasant," at green-blue, while for the same curve, "most pleasant," it is divided between green-blue and blue; whereas for the rest of the curves, the maximum is at green. The same is valid for the orange, where also several of the curves have their maximum at the green-blue, which is the nearest to the complementary. Orange-yellow and yellow have also one maximum each, nearest to the complementary, but the latter (yellow) not an undisputed maximum, and the former only in the combination Curve *c* for the "pleasant."

For the rest of the curves, one can say decidedly that a colour somewhat approaching the complementary has the preference, but it is never the one which among our twelve qualities would be the *nearest* to the complementary. Thus for green we find throughout all the curves red in the maximum, while the complementary to green is beyond the purple towards violet-purple. In green-blue we find red and orange chiefly the maximum, whilst the complementary is at orange-yellow. One must not be misled by the names of the colours; the green-blue of the pure colours was by no means identical with the green-blue of the pigment colours of our former experiments (15), as the difference in the complementaries shows. For blue we find in two of the six curves again an inclination towards a preference for the complementary, but there are always other maxima as well, and the colour in question, yellow, has no better claim than the next colour, yellow-green. For violet, violet-purple and purple, yellow seems to have the preference, and not once

does the maximum coincide with that one of our twelve qualities which is nearest to the complementary.

We see thus that the trials with spectrally pure colours essentially substantiate the results obtained with pigment colours. Although the two sets of experiments cannot be directly compared, partly on account of the introduction of changed space relations, partly on account of the different choice and number of qualities, the trials with pure colours distinctly show again that the colour which has the preference is always one somewhat related to the complementary, but scarcely ever the latter itself. Thus *there is very little justification for the old dictum of the maximum pleasantness of pairs of complementaries.* Our experiments with pure colours make it evident also that the shape and mutual space relations of the components have a great influence. The detailed report of this phase of our results will appear in a third article.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R OR O OY Y YC C CB B V VP P R
I (a)
25
20
15
10
5
R OR O OY Y YC C CB B V VP P R
I (b)
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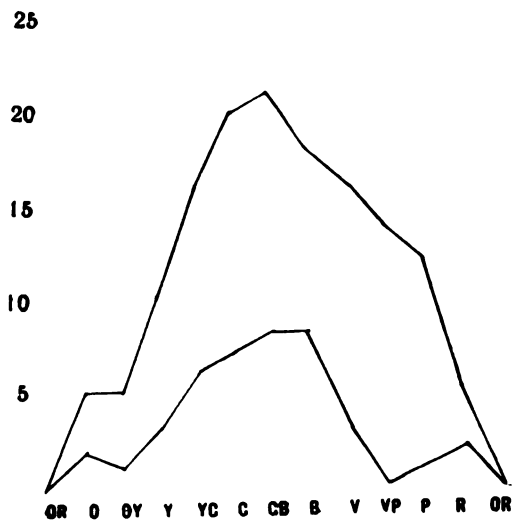
20
10
R OR O OY Y YC C CB B V VP P R
I (c)

RED



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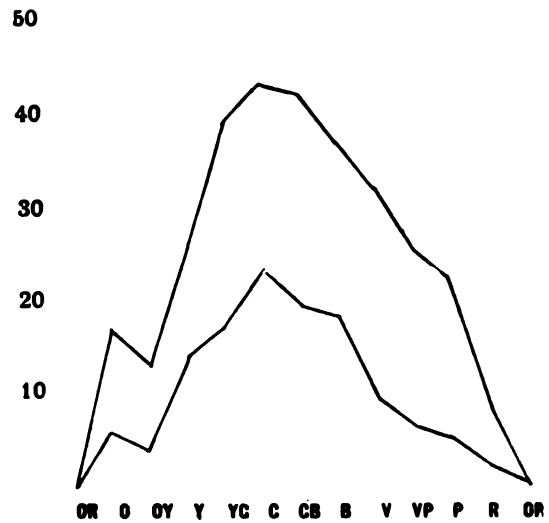
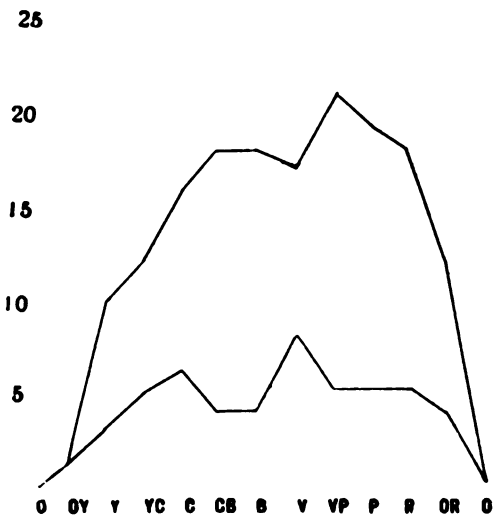
2 (b)



2 (c)

ORANGE-RED



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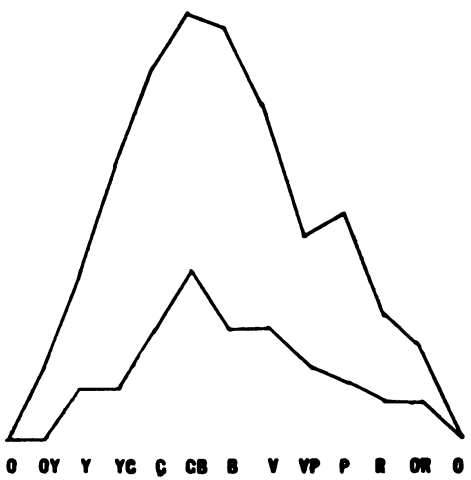

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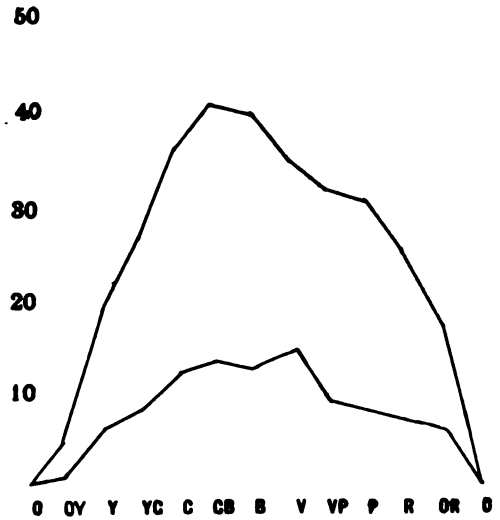

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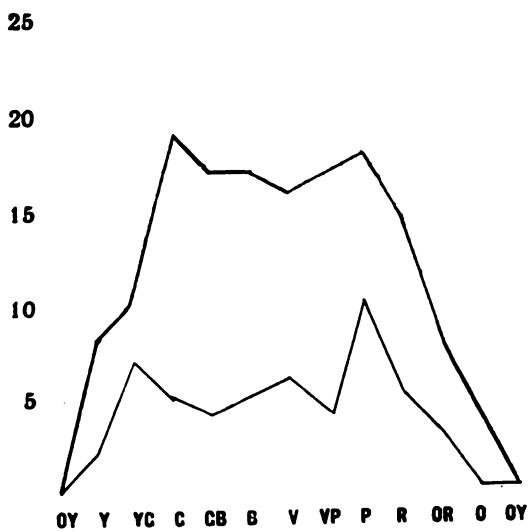
ORANGE



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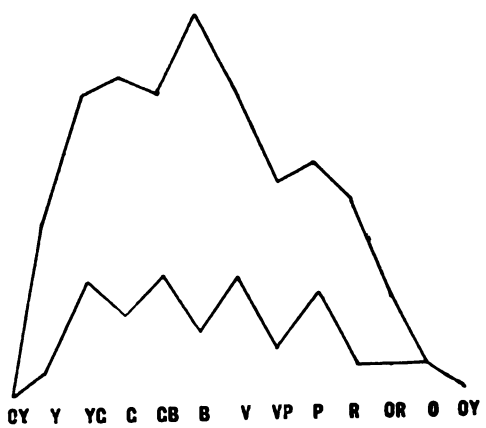

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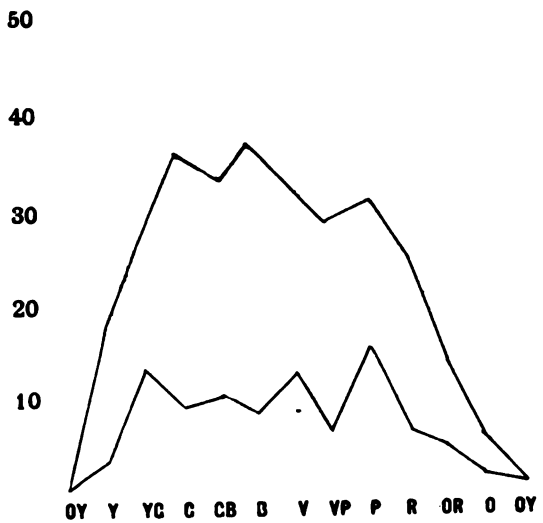

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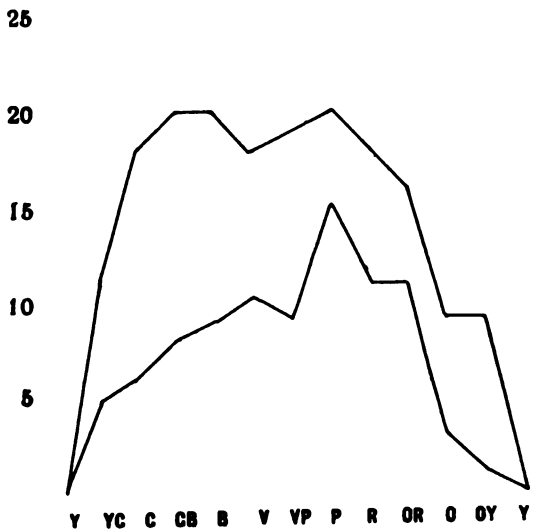
ORANGE-YELLOW



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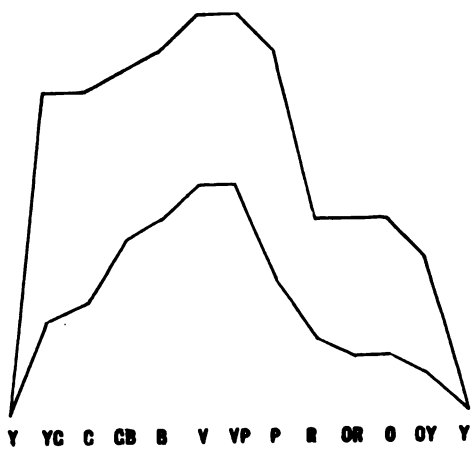

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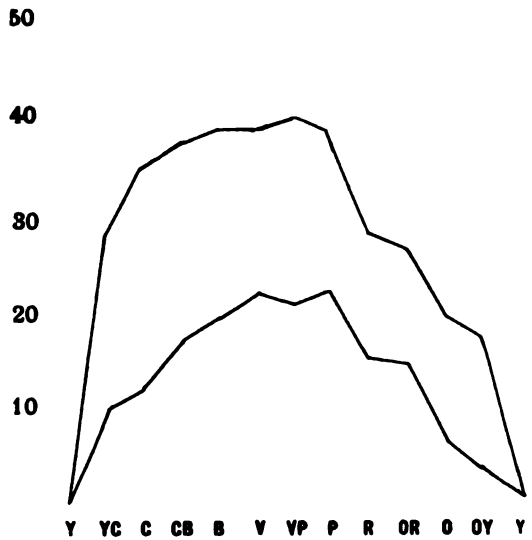

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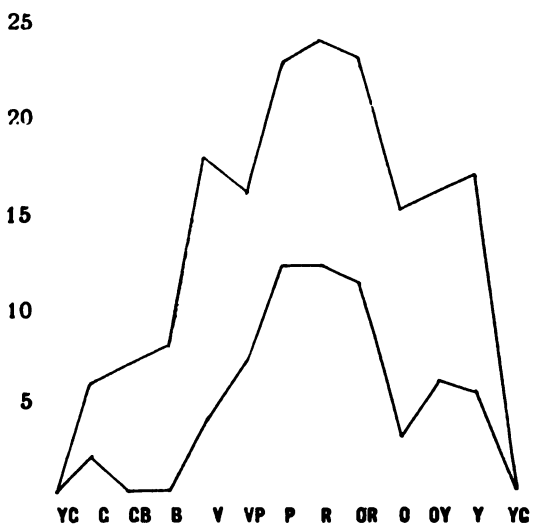
YELLOW



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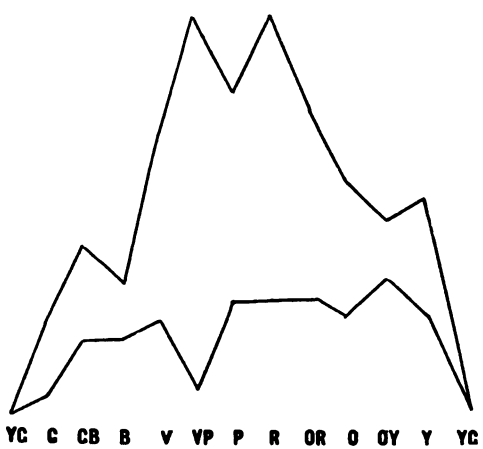

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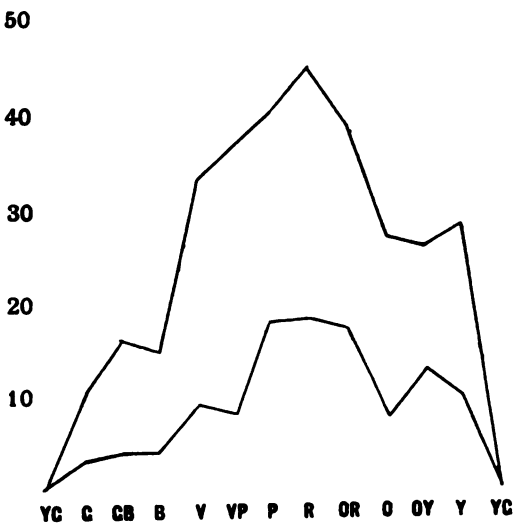

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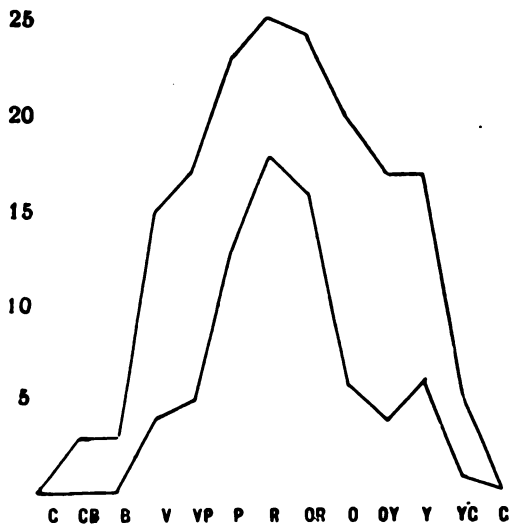
YELLOW-GREEN



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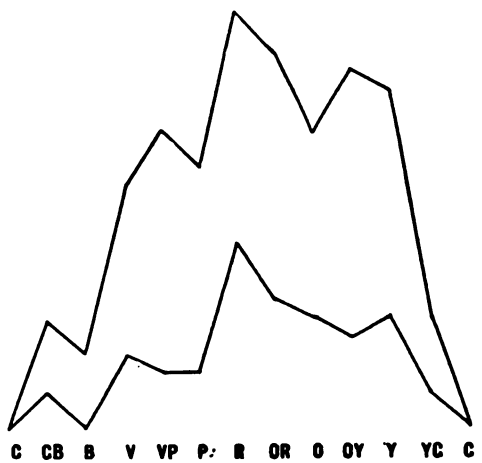

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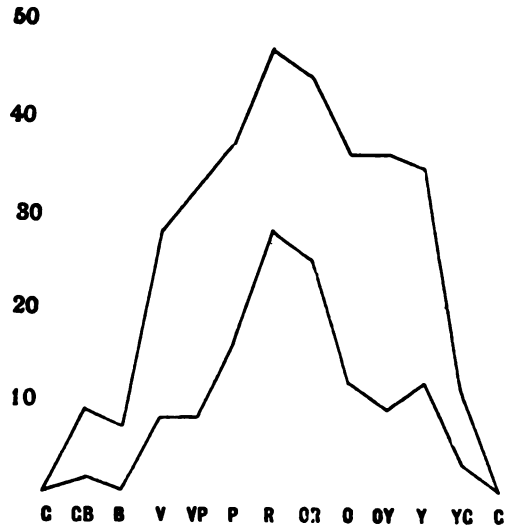

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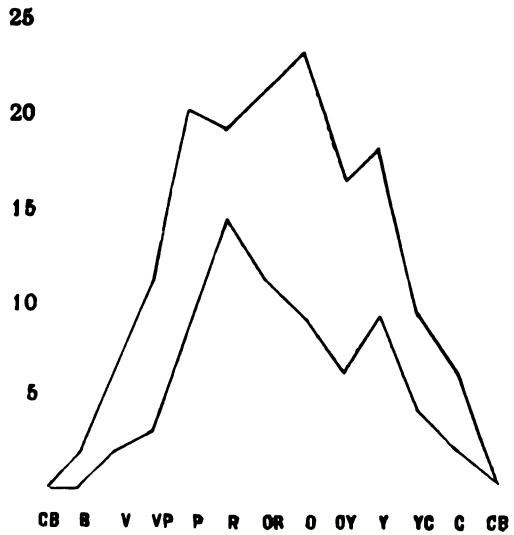

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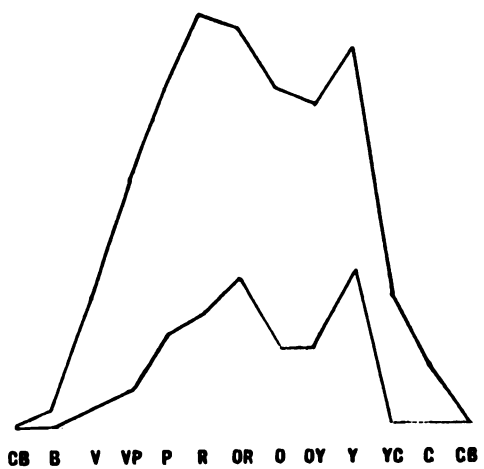

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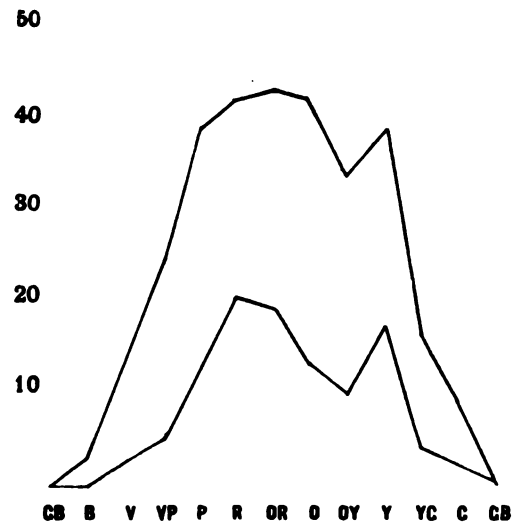

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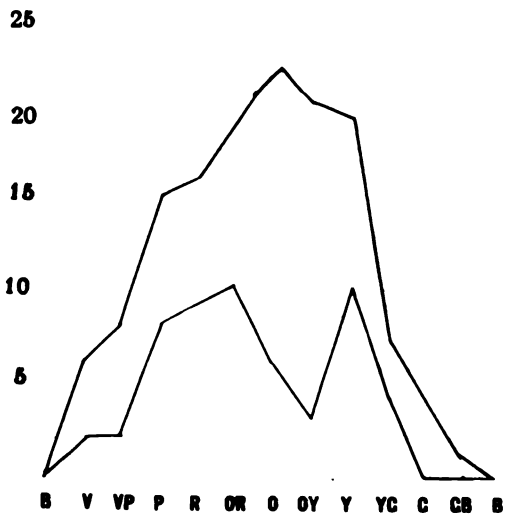
GREEN-BLUE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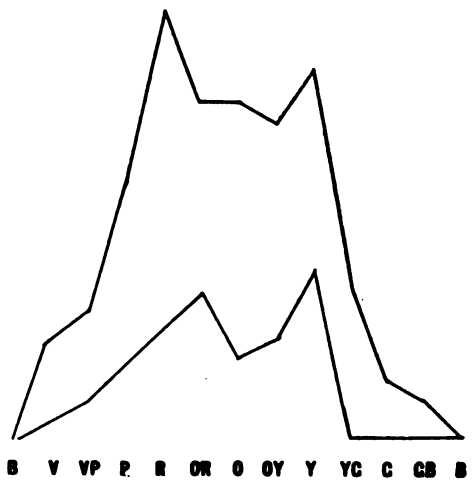
9 (a)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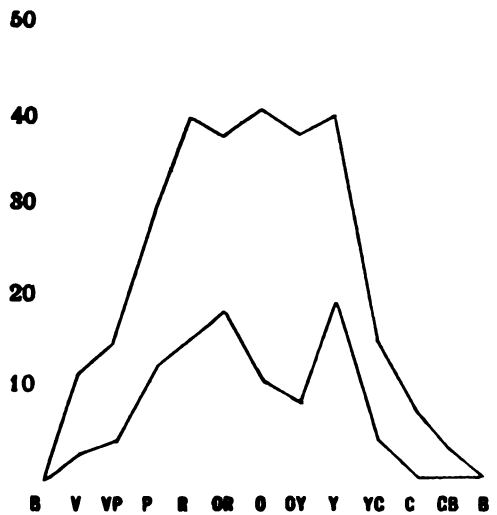
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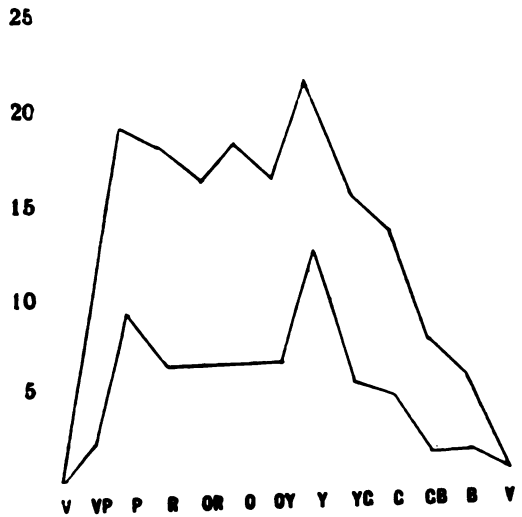
9 (c)

BLUE



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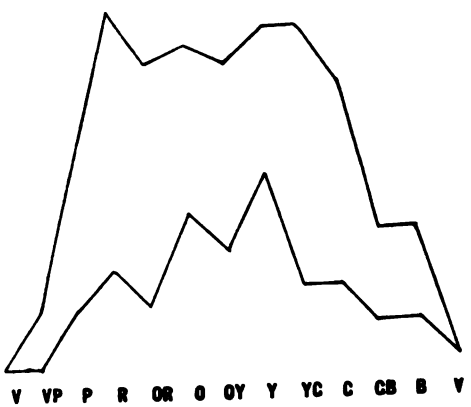

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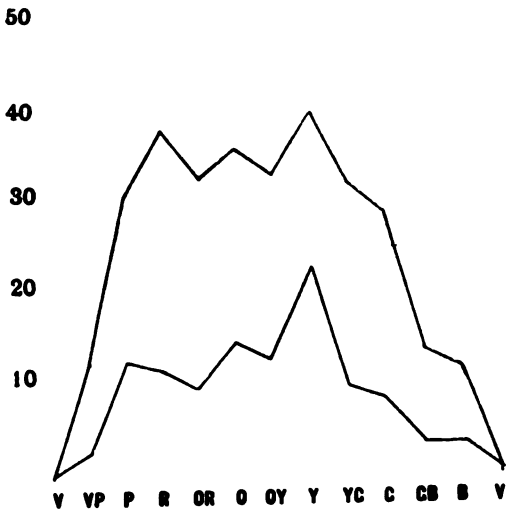
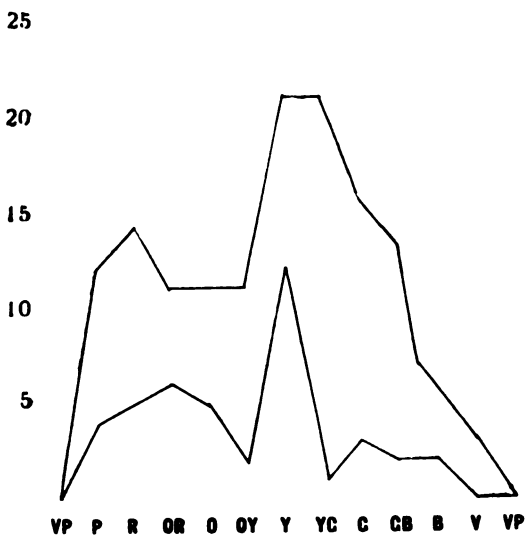


10 (c)

VIOLET



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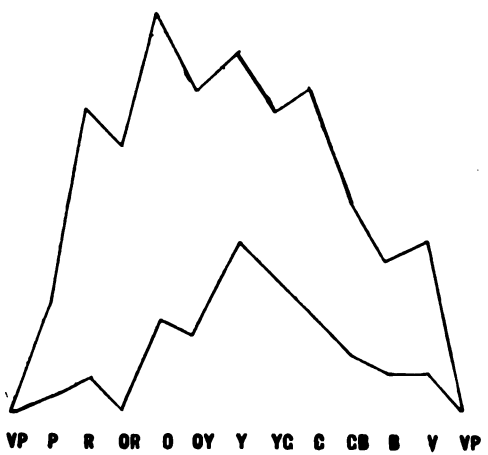
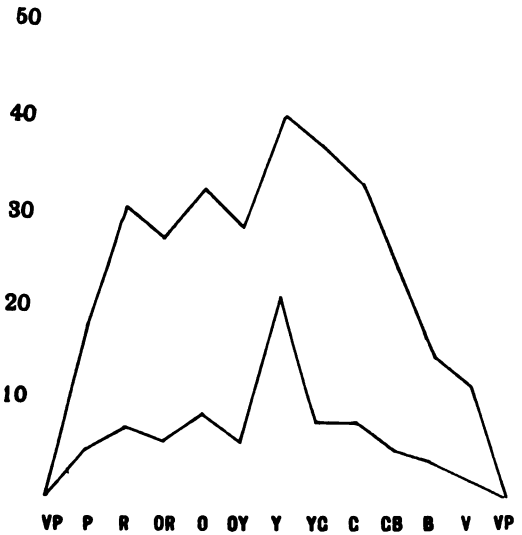
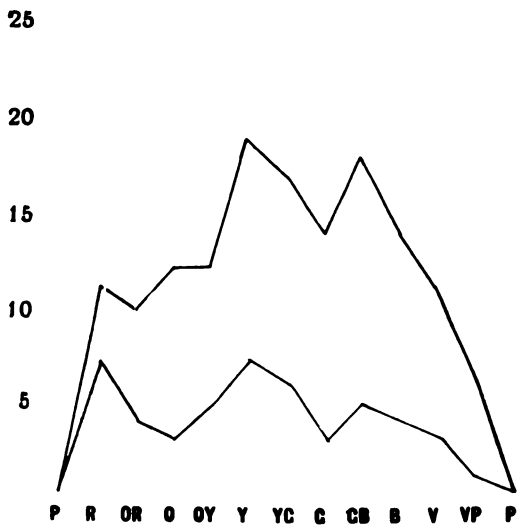


11 (b)



11 (c)

VIOLET-PURPLE



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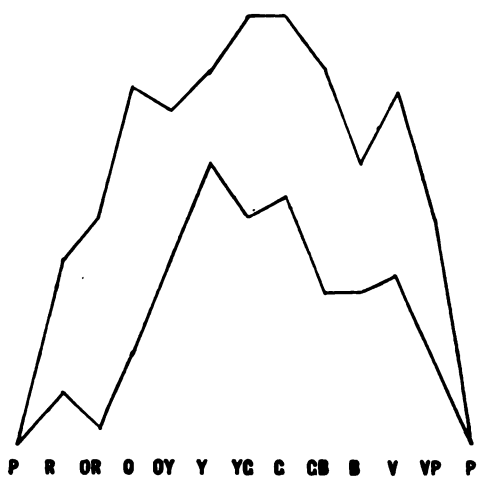

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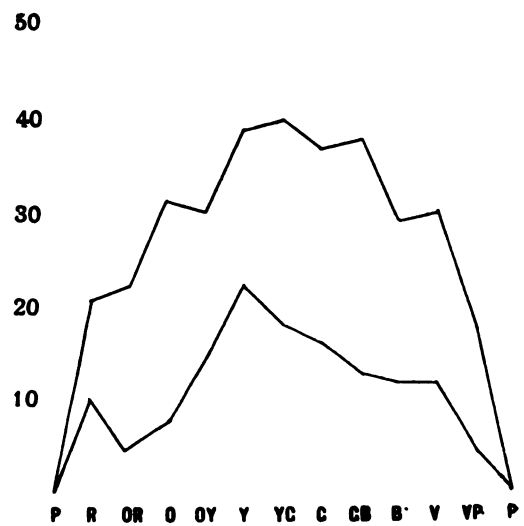
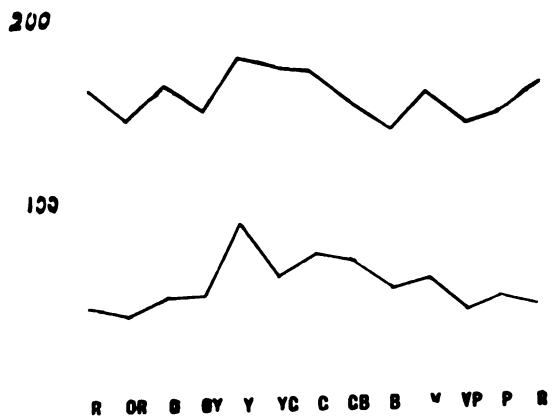


12 (c)

PURPLE



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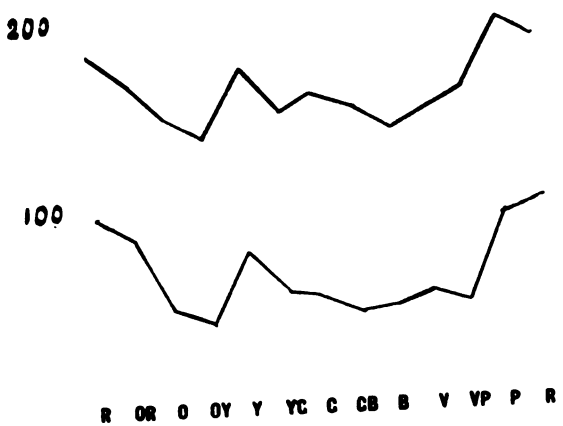

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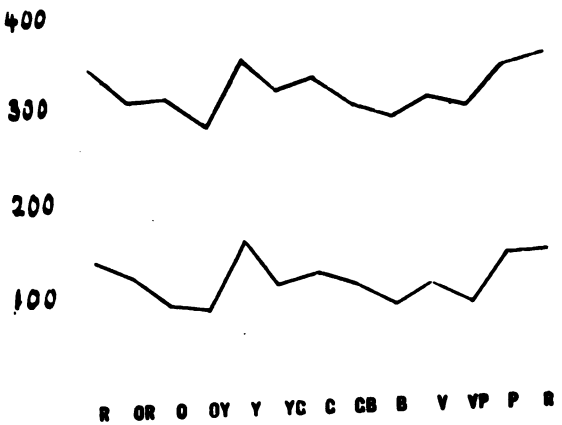

13 (c)

COMBINATION-CURVE

ON COLOUR-PHOTOMETRY

AND ON SOME QUANTITATIVE RELATIONS OF THE PHENOMENON OF PURKINJE

BY

R. J. WILSON, M.A.

ON COLOUR-PHOTOMETRY AND ON SOME QUANTITATIVE RELATIONS OF THE PHENOMENON OF PURKINJE.

There are three ways known of measuring differences of intensity in light sensations of different colour quality. The first is to insert a small sector of colour in a white or gray disc and rotate the disc. The intensity of the gray will be changed, but there will be no colour perceptible, *i.e.*, while to a certain extent the introduction of colour may change the intensity, it does not necessarily follow that it must produce a distinct colour quality.[1] The addition of the colour will cause a change, which will be above the threshold with regard to light intensity, but not with regard to colour quality. The addition necessary in order to cause a just noticeable change in intensity will differ for the different colours, and will be inversely proportional to their brightness.

A second method is that of the flicker photometer, as described by Professor O. N. Rood,[2] who found that "the accuracy attainable with the flicker photometer as at present constructed, and using light of different colours almost spectral in hue, is about the same as with ordinary photometers using light of exactly the same colour."

The third method, which we have used in the following experiments, has been described by Kirschmann,[3] and later by Professor Gruber,[4] who apparently did not know the work of Kirschmann.

It is well known that the manifoldness of colour tones decreases with the approach to the extremes of light intensity. This change of colour, the saturation being constant, is only within certain limits independent of the intensity, and in the

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[1] Kirschmann, *Ueber die quantitativen Verhältnisse des simultanen Contrastes* (Philosophische Studien, Vol. vi, page 10).

[2] For description of this apparatus *vide* Rood, *Flicker Photometer* (Amer. Jl. of Science, 4th Series, 1899).

[3] *Op. cit.* pp. 50 *et seq.*

[4] Gruber, *Untersuchungen über die Helligkeit der Farben* (Philos. Stud., Vol. ix, pp. 429-446.)

most recent spacial representation of light and colour sensation is provided for by giving the base of the colour cone an inclination towards the axis, so that yellow occupies the highest, blue-violet the lowest position. "The only pair of complementary colours which have their maximum saturation at equal intensities must therefore be at the ends of that diameter of the base which stands at right angles to the axis, and this condition will be satisfied somewhere near red and blue-green."[1]

It has sometimes been maintained that black can be seen better on a white background than white on a black background, and examples of printed letters are cited in proof. This is true only because we have shaped our letters in such a way that they are adapted for the use of black on white; the irradiation being different when white is the surface of the letters rather than the background. Similarly Von Zahn has said that yellow on a blue background and green on red are more easily seen than blue on yellow and red on green, and he attributes this to the qualities of the colours. But if there is such a difference, it must be due to intensity rather than to colour quality. For if we place, for example, a black surface one inch square concentrically upon a white cardboard square of twenty inches to the side, we shall have 399 square inches of white and one square inch of black. Let us assume that the intensity of black to white is as 1 to 50. Then we have the intensity of the whole surface equal to 399 x 50 plus 1; and if the whole surface had been white, we should have had an intensity of 400 x 50. So while the whole intensity would be 20,000, the existence or non-existence of the black square conditions a difference of intensity of $\frac{49}{20000}$ of the total intensity. On the other hand, if the large surface is black, it has a total intensity of 400, and the white square will now cause an increase of $\frac{49}{400}$ to the total intensity.

The same is the case with yellow on a blue background, owing to the great difference of intensity of the colours, yellow being like white, and blue like black, if highly saturated pigment colours are used. We may calculate by the above

[1] Kirschmann, *Colour Saturation etc.* (American Journal of Psychology, Vol. VII, p. 394.)

method the possibilities in the change of intensity by the superposition of each on the other, and it will be easily seen that a yellow object placed on a blue background will condition a much greater change in the total intensity than blue on yellow.

As to the possibility of comparing differently coloured lights with regard to their intensity, and consequently as to the measurement of the brightness of colours, there are widely different views held. Whilst Münsterberg, for instance, claims that the impressions of even completely different senses can be compared with regard to their intensity (in terms of muscular sensations), there are others who would scarcely admit that even two different colour sensations can be so compared. Most of those, however, who hold the latter view have never made a serious attempt to investigate the facts. The very fact that colourless light can always be regarded as the saturation zero of any colour should convince everybody of the feasibility of the photometry of colours, even if only indirectly by comparing them with colourless light.

Hering holds that every one of his four fundamental colours exerts, apart from its perceived intensity, a brightening (in the case of yellow or red) or darkening (in the case of green or blue) influence. Hillebrand has tried to establish this standpoint of Hering experimentally. In weak illumination coloured objects look colourless; at the same time they change their intensity value, as is necessary according to Purkinje's Phenomenon. Hillebrand determined in a dark room the intensity value of a variable ring of black and white. Having obtained these values, he made, by means of discs, a series of mixtures of colour with black and white for which the intensity value should have been the same, and then compared these discs with one another in full daylight. He found then that they showed intensity relations very different from those which they had in weak illumination.

Helmholtz had come to the following conclusion regarding the possibility of exact comparison of coloured and uncoloured light. "One can compare different colours," he says, "with regard to intensity, but the certainty and exactness of such comparison is far less than in the comparison of lights of the same

colour." He states that he frequently found great difficulty in making exact judgments.[1]

The most recent investigation of the subject is the above-mentioned article of Professor Gruber entitled "Experimental research on the brightness of colours." Gruber's way of stating the intensity of the illumination by saying that it was bright daylight—greater or less—is rather unsatisfactory and inexact. For it may be demonstrated geometrically that at the equator, for instance, at the solstices, if at noon the total illumination be represented by 1, one hour after sunrise it will be represented by very little more than ¼ (0.259), at twenty minutes after sunrise by less than 1/10 (0.087), and at four minutes after sunrise by less than 1/50 (0.0174). Similarly in the afternoon there will be a corresponding diminution in the intensity of the illumination from noon till sunset. We can illustrate this fact by an experiment with a blue-green colour disc in a room where the intensity was reduced by tissue papers covering the aperture through which the light was admitted and varying from 0 to 60 in number. At 3 p.m. the disc was plainly visible though the colour could not be distinguished at an illumination through 50 tissue papers, at 5 p.m., when only 40 papers covered the aperture, the disc was not visible at all. Therefore bright daylight is a rather flexible term, for one-fiftieth of the bright daylight at noon is still judged as *bright daylight* early in the morning and late in the afternoon.

Professor Gruber does not seem to have been cognizant of the previous publication on the same subject by Kirschmann in the above-mentioned article on contrast. In order "to gain a further control, he made trials with changed intensity and changed saturation." The value of these trials is not clear to us, and the change of intensity would seem to make the control valueless. Real control trials are only those where a constant intensity is assumed; for by changing the intensity the very factor is introduced (Purkinje's Phenomenon) which makes the control questionable. The total result of the trials with constant intensity was that "a mere change of saturation does not condition a

[1] Helmholtz, *Physiological Optics*, p. 238.

change of intensity." Kirschmann's control-experiments had already shown this.

The way in which Professor Gruber tries to reconcile this result with the hypothesis of Hering's "White-Valenz" theory, which it contradicts, is extremely interesting. When not only changes of saturation but also changes of intensity were made by the addition of white or black, great deviations were observed. When white was added the observed values were almost always too dark, while additions of black made the deviations considerably smaller; for one observer there were no deviations at all. This may easily be accounted for by the fact that all colours in higher intensities tend toward white; in lower intensities toward black. For example, if a red mixed with white be used, not only is the saturation lowered, but at the same time the intensity of the red is increased, and consequently its effect must be different, according to the phenomenon of Purkinje. The results of these trials, which, as control trials, appear extremely questionable and by no means numerous enough, he explains by contrast and by the fact of the observer becoming accustomed to a certain gray. One can see how far this "being accustomed" can really go from the following case which Gruber himself adduces, and which indeed seems quite characteristic of his whole series of control trials. A trial with constant intensity was intended to be made, and it was intended to add to a blue disc 10° white and 61° black, but by mistake they added 10° black and 61° white; the observer found the intensity *almost the same, there being only a very slight difference*: the observer *believed* that the intensity was not changed. Gruber concludes that it is possible, with the necessary practice of the observers, to carry out comparisons with exactitude to within a few degrees, which agrees well with the previous results of Kirschmann.

Gruber made an interesting series of experiments in order to compare values gained in daylight with those which for the same colour discs and the same observers, according to Hering's and Hillebrand's method, were obtained in weak illumination. The rotation apparatus was set up in a dark room to which light was admitted through a narrow slit covered with a milk glass.

After the observer's eye had become accustomed to the weak illumination, the disc looked gray on rotation and could be compared with black and white discs. It was found, exactly as Hillebrand had stated it, that in this illumination red and yellow were relatively darker and green and blue relatively brighter than in daylight.

The experiments which Gruber conducted in a dark room with a colour-blind seem further to show the impossibility of Hering's special "White-Valenz" theory. It has several times been emphasized that the disappearance of colours in weak illumination corresponds to the vision of total colour-blinds for whom remains only the excitation of the black-white substance. Hence for them the normal intensities of the colours must be those which *we* see in weak illumination, and therefore to a red-green colour-blind green should look brighter and red darker than to an eye of normal colour sense. He found, however, that while the original trial for green gave a 6° darker value than for normal persons, yet in the dark room green looked 13.5° too bright, and in the control trials the values always appeared a little, though not much, too bright. The colour-blind with whom Gruber conducted his experiments was a decided dichromat but with a shortened spectrum almost to the D line. The indifference line was at or near E; the violet side of the spectrum was not shortened. One need only say that under such conditions no wonder that red looked darker than to an eye of normal colour sense.

In the experiments which we conducted on the intensity of colour pigments in different illumination, the apparatus used was that of Dr. Marbe made by Zimmerman and altered to suit the particular needs of the case. The discs used were of Milton-Bradley coloured paper on a black and white background. The ring of colour was a constant, the gray a variable quantity. The intensity of the light was relatively controlled by conducting the trials in a room admitting daylight through a square window of forty by forty-eight inches, then through a small square opening one-twelfth the size of the window, which was further successively covered by 5, 10, 20, 30, 40, 50, and 60 white tissue papers.

In order to find the relative intensity of the light for each of the series of trials, two sets of experiments with the episcotister were made, one with Professor Kirschmann as an observer, the other with the writer. It was found that for sunlight, plain daylight, daylight through the aperture, and for 5, 10, 20, 30, and 40 tissue papers, approximately accurate measurements could be obtained, but for lower intensities the results had to be computed from the data already obtained. The following table shows the intensities used in our experiments: [1]

If for bright sunlight the intensity be called				100,000,000
Then for plain daylight the intensity was found to be approximately				10,000,000
And for the aperture,			(approximately)	800,000
" "	5	tissue papers,	"	40,000
" "	10	" "	"	5,000
" "	20	" "	"	500
" "	30	" "	"	40
" "	40	" "	"	8
" "	50	" "	about	2
" "	60	" "	"	1

[1] These empirically ascertained results do not agree with the demands of the physical theory of absorption. Theoretically if one diffusely transmitting plate (ground glass, tissue paper, etc.) permits the passage of $\frac{1}{x}$ of the incident light, the quantity of light transmitted through n plates ought to be $\frac{1}{x_n}$! The reasons for the deviations may be sought in the following circumstances.

1. No transmission of light is absolutely diffuse. There is always a quantity of light the path of which assumes the form of a more or less *regular* refraction. The passage of this refracted and probably polarized light finds with every additional plate more favourable conditions.

2. The light which is not transmitted is partly absorbed, partly reflected. The posterior surface of each plate must throw back again a part of the light reflected from the plates behind, and thus increase the quantity ready for transmission.

I believe that these conditions have a certain bearing also on the theory of absorption in general. It is always assumed that the absorption follows the rule:

$$I = \frac{1}{x^d}.$$

where I designates the quantity of light transmitted, whilst d stands for the thickness of the absorbing body and x for the absorption-coefficient of the substance in question. This absorption-coefficient can be ascertained then by the formula

$$\log x = \frac{\log \delta}{-d} = \frac{-\log \delta}{d}$$

A double series of trials was made for each colour; in the one case commencing at fullest illumination and going down towards lowest intensity; in the other commencing with the lowest and approaching the highest illumination.

It should be remarked at the outset that some observers begin with the prejudice that it is impossible to judge the intensity irrespective of the colour. It cannot be denied that the presence of colour does make the judgment more uncertain—often very considerably—but with practice this uncertainty is much reduced. We therefore found it valuable to make first a large number of practice-experiments in a constant intensity of illumination (daylight), to accustom the observer to the colour and to making exact statements. We used the conscious method. The series of observations made by Professor Kirschmann were the only ones obtained by the unconscious method.

Gruber found that the mean variation for blue was conspicuously great. One would have thought that this would invalidate his statement about yellow, where he says that the mean variation for yellow is also especially great, and accounts for such behaviour by the fact that yellow is much brighter than the other colours, and that the discriminative sensibility follows the law of Weber. With regard to the blue, however, he accounted for the greater inaccuracy by attributing it to the circumstance that, the trials with that colour being made first, the observers had not yet sufficient practice; he refers also to other disturbing influences. With the blue we found that uniformly there was no diminution of intensity with the decrease of the illumination; on the contrary in most cases the number of degrees was highest in lowest illumination.

In all colours with which we experimented the mean variation was naturally the highest in lowest intensities. This was to be expected, owing to the increased difficulty in seeing the colour disc in the dark. In the first trials there were frequently

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This may be correct for perfectly transparent bodies (regular transmission) as coloured glasses or liquids, smoked glasses, etc., but it can never be correct for diffuse (i.e. irregular) transmission, e.g. with paraffin, opal glass (milk glass) thin films of metal, etc., where a considerable amount of light is lost through reflection, from the front surface as well as from a certain depth.

A. KIRSCHMANN.

very much greater deviations than in subsequent trials. In the case of all the colours, as the colour faded there was still perceptible a difference of intensity between the rings of gray, and the experiments were continued with these until the intensities became too low to see the discs at all.

The highest average mean variation for the whole series of blue for an individual observer was 8.09 (Professor Kirschmann) the lowest was .8614 (Mr. McLeod). The average mean variation for eight observers in all the series of blue and in all intensities was 3.45. It will be remembered that for one intensity the average mean variation of the five observers in Professor Kirschmann's experiments in Leipzig above referred to was approximately 2.5. When the intensity was reduced by twenty tissue papers there was still a bluish colour visible; at 30 all trace of colour was gone, though the intensities could still be judged when 40 and 50 tissue papers covered the aperture. In all the colours it was found to be much more difficult to make comparisons when the colour was distinctly present. In the blue there was with the decrease of the intensity a steady increase in the number of degrees added, though there occurred an occasional fluctuation. The results obtained by Allen and Wilson are exceptional in this regard, probably in consequence of the disturbances in the illumination caused by a cloudy sky (sun-shine interrupted by snow-flurries).

Omitting these two series the average intensity extends:
in full illumination from 35.5° to 68.34°;
with aperture open from 37.7° to 59.8125°;
with 5 tissue papers from 44° to 65°;
with 10 tissue papers from 38° to 54°;
with 20 tissue papers from 50° to 58°;
with 30 tissue papers from 52° to 56°.

In the blue-green the tendency was rather a decrease in the number of degrees from full intensity down to 20 tissue papers covering the aperture, and from that to the lowest intensity a steady increase in every case. At 20 the observer could not tell whether the colour was blue or green but inclined to call it blue. At 30 the colour was far more blue than green. At 40 it was almost gone but there were still faint traces of blue. For lowest

intensity the average mean variation was approximately 12. One observer saw blue-green quite differently to the others, his results being much higher though quite consistent with those of the other observers. This leads one to notice that there are individual differences with regard to the intensity of colours even among persons of normal colour sense, and that this question deserves, like so many other questions whose answers are taken for granted, a more thorough investigation than has yet been accorded it.

Violet showed a consistent downward tendency with the decrease of illumination, from an average of 52.77° in highest illumination to an average of 42.34° when 30 papers covered the aperture. The decrease was nowhere large; there being in the violet used more of blue than of red, it gave a very slight though regular diminution with the falling intensity. When 20 tissue papers were added the observer could no longer see colour. In the trials beginning at lowest intensity of illumination and advancing towards the highest, the colour re-appeared when ten tissue papers covered the aperture, but in making eight trials in this intensity the colour appeared and disappeared several times. The average mean variation at highest intensity for all observers was 3.93; at lowest intensity it was 6.048. The average mean variation for the whole series of violet was approximately 4.

Green showed a consistent downward tendency till 30 tissue papers controlled the illumination; but when colour was no longer present the number of degrees rose when 30, 40 and 50 papers respectively covered the aperture. The tendency downward in red was in every case observable. In lowest intensity while there was still a trace of red left it was immediately judged darker than the black disc on which it was mounted. This we proved for one observer by inserting a sector of 60° white superposed upon the red ring of the disc. Orange-red was very much higher but exhibited the characteristics of red throughout. In full intensity the extremes were from 51.83 to 99.61 while only from 15.25 to 28.125 in lowest intensity. Orange also showed a regular downward tendency, the extremes at full intensity being 51-135 and at lowest intensity 15-69.

Yellow was for all observers always difficult to judge, ranging from nearly cream colour in lowest intensity through a yellow with a tinge of orange in it up to a bright yellow. As others have already pointed out, the mean variation was extremely large and the judgments varied considerably for different observers and on different days.

In the tables I to VIII (pages 58-65) the upper number always indicates the number of degrees of white contained in the gray that was found equal in intensity with the coloured ring. The lower number gives the mean variation in degrees.

After the experiments with pigment colours in reflected light, it was found desirable to make a few trials also with transmitted light and with spectrally purer colours. A new double episcotister, which will be described elsewhere by Professor Kirschmann, was constructed for the purpose. The obscuring sectors could be varied whilst in motion. The small aperture in the window was provided with a shutter through which two circular holes of one inch diameter were made. On the outside of the shutter was an arrangement to hold absorbing plates which intercepted the incident light. Three colours were thus examined. The first was a combination of gelatine plates which allowed no rays to pass through except those between the red end of the spectrum and 604 $\mu\mu$. The second was a green composed of different green, yellow-green, and blue-green gelatines, which reduced the light transmitted to the region of 563—494 $\mu\mu$; the third was a blue which absorbed all waves longer than 492 $\mu\mu$. Both holes were also obscured by tissue papers till in full opening of the episcotister the intensities of the two were judged equal. Before these openings rotated the double episcotister at a speed of over 50 revolutions per second driven by an electric motor. Now if one of the two apertures was coloured, the other uncoloured, and they were, by means of tissue papers and episcotister, brought to apparently equal intensities, then an equal reduction of intensity, by increasing the obscuring angle of the episcotister, would make them appear unequal; which inequality could be again compensated by an additional subtraction of light from the brighter aperture. The three tables IX to XI (page 66) contain the results.

TABLE I.—BLUE.

Observer.	Hour.	Kind of Day.	Full Window	Smaller Aperture.	5 T P*	10 T P	15 T P	20 T P	25 T P	30 T P	40 T P	50 T P	60 T P
G. F. N. Atkinson..	11 a.m.	Dull	50.625 2.28125	53.375 2.75		47.4375 2.4375		56.0625 2.6875		56.0625 8.0625			
D. J. Davidson....	11 a.m.	Bright	41.8125 3.9375	40.75 3.875		19. 3.125		58.8125 4.3425		52.6875 13.5625			
A. S. Kerr.....	11 a.m.	Bright	55.745 1.935	48.625 1.75		38.06 1.855		50.06 2.09		54.499 3.622			
A. H. McLeod.....	2 p.m.	Bright	43.925 .805	49.515 .835	57.055 .995		54.435 .01			53.155 .905			
R. S. Laidlaw.....	2 p.m.	Bright	68.34375 .59375	59.8125 .50	65.8125 1.065		60.375 1.875			19.59375 .21375			
A. Kirschmann	3 p.m.	Dull Av. Hazy	34.5 6.	37.7 4.1	44. 7.85	54.375 9.94		50.25 9.75		53.375 5.125	63.375 10.72	71.25 11.25	
W. K. Allen†.....	2 p.m.	Bright	89.9375 3.4625	78.5625 3.5465		58.9375 3.9375		52.1875 3.7965		48.5625 2.9685			
R. J. Wilson†.....	2 p.m.	Bright	93.0125 2.4375	73.5 1.875	73.75 2.125	63.5 1.75		46.875 1.8435					

*T.P.—Tissue Paper.

†A disturbing influence of snow and bright sunlight present.

TABLE II.—BLUE-GREEN.

Observer.	Hour.	Kind of Day.	Full Window	Smaller Aperture.	5 T P	10 T P	15 T P	20 T P	25 T P	30 T P	40 T P	50 T P	60 T P
G. F. N. Atkinson..	11 a.m.	Cloudy	126.048 3.845	125.475 4.		114.875 3.425		118.825 3.45		119. 7.1675	117.6875 19.545	144. 12.5.	
D. J. Davidson	11 a.m.	Bright	94.54 3.68	98. 3.49		100.75 4.028		107.375 5.5555		110.5 6.5325	109.375 15.125		
A. S. Kerr	11 a.m.	Clear	95.7175 2.6675	95.4025 2.255		84.7475 2.8175		83.8725 3.0375		90 7025 4.785	92.623 3.66		
A. Kirschmann	3 p.m.	Bright	99.375 8.625	93.5 3.125	87.75 5.25	81.25 5.50		71.5 5.5		92.125 4.625	106.625 9.375.		

TABLE III.—VIOLET.

Observer.	Hour.	Kind of Day.	Full Window	Smaller Aperture.	5 T P	10 T P	15 T P	20 T P	25 T P	30 T P	40 T P	50 T P	60 T P
G. F. N. Atkinson..	11 a.m.	Bright	57.5 3.515	49.8125 2.9825		47.125 2.469		48.1875 3.3125		46.25 7.859			
D. J. Davidson	11 a.m.	Bright	49.375 3.86	49.1875 3.36		47.1875 3.5625		43.875 4.125		40.25 8.3125			
A. S. Kerr	11 a.m.	Bright	57.81 2.445	50.81 2.57		45.12 2.575		44.5 2.8125		41.8125 2.62			
A. Kirschmann	3 p.m.	Bright	50.2 5.9	45.9 3.625	45.5 3.625	45.4 2.8		44.5 4.25	44.25 4.7	41.1 5.4	43.25 4.7.		

TABLE IV.—GREEN.

Observer.	Hour	Kind of Day	Full Window	Smaller Aperture	5 T P	10 T P	15 T P	20 T P	25 T P	30 T P	40 T P	50 T P	60 T P
G. F. N. Atkinson	12	Cloudy	95. 2.75	90.5 2.5		94.25 3.		89.25 3.375		104.75 9.06			
D. J. Davidson..	12	Cloudy	83.625 4.125	88.5 2.875		95.625 5.125		91.5 5.125		105. 12.5			
A. S. Kerr.....	12	Bright	95. 3.25	97.5 3.		88. 2.25		86. 2.50		91.37 1.97	92.25 3.31		
R. S. Laidlaw...	2	Bright	109.375 1.4375	107.21375 1.53125	115.09375 1.65625		109.4875 1.59375			114.6875 3.9375	115.59375 3.84375		
S. H. McLeod .	2	Bright	103.526 1.53	106.5 .875	107.995 1.185		109.95 .156			116.555 1.495	115. 2.43		
W. K. Allen...	2	Bright	110.4375 2.2185	108.675 2.5625	107.9375 2.3125	108.8125 2.2185		108.9375 3.21875		103.4375 2.4685			
R. J. Wilson....	2	Bright	106.625 2.	105.9375 2.1875	107.125 2.90625	106. 2.25		105.4375 1.71875		105.375 2.46875			
A. Kirschmann .	3	Bright	105.875 11.343	102.5 8.75	99.25 7.2	98.5 5.875		95.625 7.47		107.125 9.16	111.375 5.5	110.625 8.5	

TABLE V.—RED.

Observer.	Hour	Kind of Day	Full Window	Smaller Ap'rture	5 TP	10 T P	15 T P	20 T P	25 T P	30 T P	40 T P	50 T P	60 T P
G. F. N. Atkinson....	2.30 10.30	Bright	36.5 1.6421	29.3125 2.3125		13. 3.25	4.375 3.	4.75 4.25					
D. J. Davidson.....	11 a.m.	Dull	24.083 3.165	21.3 3.5208		15.4166 2.723	7.3125 3.75	4.75 3.625		3.25 3.875			
A. S. Kerr.....	11 a.m.	Bright	38.685 2.37	35.625 2.575		26.75 2.31	19.25 1.185	16.495 1.775	9.75 2.25	3.75 1.82			
S. H. McLeod.....	2 p.m.	Dull	23.515 .4225	25.529 1.315	26.2775 .84	16.06 1.00		49.0625 2.1875	43.78 .735	35.81 2.935			
W. K. Allen.....	2 p.m.	Very Bright	78. 1.7965	69.8125 3.4375	61.4375 2.40625	54.125 2.6875		39.0625 2.4375	25.4375 2.23435				
A. Kirschmann	3 p.m.	Bright	31.375 6.532	28.125 4.656	24.875 4.219	22.875 3.8125		17.875 2.656	Traces of Red but immediately too dark.				

TABLE VI.—ORANGE-RED.

Observer.	Hour.	Kind of Day.	Full Window	Smaller Aperture.	5 T P	10 T P	15 T P	20 T P	25 T P	30 T P	40 T P	50 T P	60 T P
G. F. N. Atkinson..	11, 2, 3	Bright	99.61875 4.10125	91.6875 4.00		85.0416 4.083		57.7083 4.1458		28.125 4.375	19.75 3.		
S. J. Davidson.....	2 p.m	Bright	64.083 3 042	58.4583 3.926		52.125 4.792		34.375 3.6458		22.83 2 708	19.625 2.33	18.125 3.575	
A. S. Kerr..... ...	11 a.m.	Dull	80.185 3.7325	73.8725 3.0125		71.4375 2.8175		49.84 3.2225		24.286 2.92	19.707 2.92	12.935 5.060	
A. Kirschmann	3 p.m	Dull	51.833 9.362	39.875 6.875	39. 10.75	25.258 7.0375		14.3 3.625		15.25 4.3125			

TABLE VII.—ORANGE.

Observer.	Hour.	Kind of Day.	Full Window	Smaller Aperture.	5 T P	10 T P	15 T P	20 T P	25 T P	30 T P	40 T P	50 T P	60 T P
R. L. Laidlaw	2 p.m.	Dull	115.5035 1.76375	103. 1.500	131.0625 7.8125		117.875 8.625						
A. H. McLeod.....	2 p.m.	Dull	120.49 4.125	129.50 .875	16.562 4.937		86.437 2.68			69.375 4.275			
W. K. Allen.....	2 p.m.	Bright	135.3125 5.39	124. 5.6715		103.25 3.	100.4375 2.85	58.5 5.375					
R. J. Wilson.....	2 p.m.	Bright	150.75 3.	113.5625 2.78125	101.9375 5.8125	86.375 2.85		58.5 5.375		88. 3.625			
A. Kirschmann...	3 p.m.	Very dull	51.833 9.362	39.875 6.875	39. 10.75	25.258 7.0375		14.3 3.625		15.25 4.3125			

TABLE VIII.—YELLOW.

Observer.	Hour.	Kind of Day.	Full Window	Smaller Aperture.	5 T P	10 T P	15 T P	20 T P	25 T P	30 T P	40 T P	50 T P	60 T P
F. N. Atkinson ...	11 a.m.	Dull	239.083 7.05183	242.83 7.625		239.7183 11.2183	240.125 6.25	238.7416 17.1875	225.75 12.265				
D. J. Davidson	12 and 3 p.m.	Bright	260.7 4.75	264.5725 4.		255.1875 5.2325		238.50 6.275	225.25 10.75	224.875 12.405			
A. S. Kerr.....	12, 9 12	Bright	236.206 4.413	252.873 4.536		264.873 4.123		263.873 4.81	263.85 6.61	274.58 5.625	293.12 5.12		
A. H. McLeod	2 p.m.	Bright	239.31 1.185	249.78 3.5925	252.78 1.34		252.715 3.15			251.11 5.86	259.055 5.871		
R. S. Laidlaw.....	2 p.m.	Bright	230.9375 9.5625	241.906 5.09375	175.15125 1.5375		186.81 3.			193.3085 .62375	182.75 4.434		
A. Kirschmann...	3 p.m.	Dull	272.125 21.65	277. 13.	277.5 11.65	285.125 10.525		288.625 8.70625		262.375 11.9475	253.375 15.125	225.125 13.58125	
W. K. Allen*.....	2 p.m.	Bright	184.125 2.625	187.0625 3.328		185.9375 2.9375	187.9375 2.3125	185.3125 3.07775	190.375 2.375				
R. J. Wilson*.....	2 p.m.	Bright	163.625 2.435	165.6875 2.3125		162.625 2.9375	160.8125 3.5675	149.1875 2.578	144.3125 2.4375				

* A differently coloured disc. Not Milton-Bradley yellow.

TABLE IX.—Colour : Red.

Produced by absorption through 3 plates of red gelatine, different in hue.

Spectroscopic Examination :

Visible part of the spectrum : From red end to 604 $\mu\mu$.
Maximum of intensity at about 630–635 $\mu\mu$.

When the aperture with the red gelatine plates was covered with 12 tissue papers and that of the white with 20, the two openings were equal in intensity. If the physical intensity of both was equally reduced, by means of the episcotister, they appeared no longer equal in brightness. But equality could be re-established by an additional obscuration of the white opening. In this manner the following equations were obtained, each being the result of four readings :

360°	Red	=	(in intensity)	360°	White ;	Red losing	0	%.
120°	"	=	"	85¾°	"	"	"	28½ "
60°	"	=	"	29°	"	"	"	51⅔ "
20°	"	=	"	7¼°	"	"	"	63¾ "
10°	"	=	"	2⅝°	"	"	"	73¾ "

TABLE X.—Colour : Green.

Produced by 4 blue-green and 1 yellow-green gelatine films.

Spectroscopic Examination :

Visible part of the spectrum : 563–494 $\mu\mu$.
Maximum of intensity at about 525–521 $\mu\mu$.

With 5 tissue papers over the red and 15 over the white the two openings were equal in brightness.

Then the following equations were obtained :

360°	White	=	(in intensity)	360°	Green ;	Green gaining	0	%.
60°	"	=	"	47½°	"	"	"	20⅚ "
20°	"	=	"	14½°	"	"	"	27½ "
10°	"	=	"	8°	"	"	"	20 "

TABLE XI.—Colour : Blue.

Produced by 2 blue, 1 violet and 1 green-blue gelatine films.

Spectroscopic Examination :

Visible part of the spectrum : 492 $\mu\mu$ to end.
Maximum of intensity about 475 $\mu\mu$.

With 12 tissue papers over the blue and 18 over the white the two openings appeared approximately equal in intensity. The following equations were obtained for greater obscuration by means of the episcotister :

360°	White	=	(in intensity)	360°	Blue ;	Blue gaining	0	%.
120°	"	=	"	97¾°	"	"	"	18½ "
60°	"	=	"	44°	"	"	"	26⅔ "
50°	"	=	"	36°	"	"	"	28 "
30°	"	=	"	17°	"	"	"	43⅓ "
20°	"	=	"	10½°	"	"	"	47½ "
10°	"	=	"	3°	"	"	"	70 "

These tables show plainly the different behaviour of the colours of the right and left end of the spectrum when their physical intensity is strongly reduced. Red loses strongly whilst blue is considerably gaining. The green in our experiments showed still a gaining tendency. But we must not forget that we had no criterion for choosing an indifferent green. The green of our experiments was probably somewhat on the bluish side. There will be a green, i.e., a certain region of the spectrum between the lines E and F, for which the apparent gain or loss of intensity in reduced illumination will be zero, and the same will probably be the case for a certain purple, somewhat midway between spectral red and violet.

EXPERIMENTS ON THE FUNCTION OF SLIT-FORM PUPILS

BY

W. J. ABBOTT, B.A., M.B.

EXPERIMENTS ON THE FUNCTION OF SLIT-FORM PUPILS.

The eye of the domestic cat is in many ways a curious and interesting optical instrument. It has a background which, for reasons as yet not thoroughly understood, is luminous in the dark; and a pupil which, unlike that of most of the higher animals, in contracting does not maintain its circular shape, but diminishes its horizontal diameter only, thus reducing the aperture for the admission of light to a more or less narrow slit. With this slit-form pupil of the domestic cat everybody is familiar, but few, even of those who are conversant with animal life, would venture an opinion as to whether the cat is the only representative of this exception to the rule. It is curious that even the most exhaustive books on zoology only occasionally make mention of the form of the pupil, and in many cases reference to the subject is not made at all. The taxidermists, even those connected with museums, are often not very scrupulous in "copying" nature when selecting the glass eyes for their specimens. But so much is sure that while the nearest relatives of the cat, *e.g.*, the lion, do not share this peculiarity, there are other animals not related to the cat family whose pupil is like that of the cat—slit-form and vertical.

In an article on the "Parallaxis of Indirect Vision and the Slit-form Pupil of the Cat,"[1] Kirschmann propounds a theory that the vertical slit of the pupil serves the purpose of increasing the accuracy of the space distinction and depth perception in the horizontal meridian. There must be a depth perception for monocular vision, especially in those parts of the total vision field which do not overlap in the two eyes; and they are by no means unimportant, for upon these regions are projected the images of the surroundings which form for man the object of his manual handicraft, and for animals the field of prey. Kirschmann claims that the data for this monocular depth perception are furnished by what he calls the parallaxis of indirect vision,

[1] Die Parallaxe des indirecten Sehens und die spaltförmigen Pupillen der Katze (*Philosoph. Studien*, IX, pp. 447-496).

that is, the difference between the visual angle (subtending at the middle point of the pupil) and the angle of regard (subtending at the rotation centre of the eye). The narrower the pupil, the greater the discrepancy between these two angles, and therefore the more accurate is the depth perception. For this reason the pupil of the human eye is contracted when focussing for near objects. The cat's interest, when seeking prey, is concentrated on the horizontal plane, and, if it is to avoid mistakes in judging distances and directions when falling upon its victims, the data furnished by the monocular and binocular vision must be most accurate in that meridian. This end is attained with the least loss of intensity by sacrificing the accuracy in other meridians, and intensifying it in the horizontal, by reducing the pupil in that direction to the smallest diameter. He claims that this form of a pupil is not the property of an animal family, but is the product of adaptation to circumstances on account of the way of living. It should, therefore, be found in very different species, but always in comparatively small animals which, while hunting their prey, keep their eyes more or less within the horizontal plane. In point of fact we find the slit-form pupils not only in the cat, but also in the fox and the beaver.

In Professor Kirschmann's article, which is a mathematical deduction of the case, no attempt is made to prove his theory by experiment. He conclusively shows that the difference between the angle of vision and the angle of regard is not so small as Helmholtz has represented it, and that all other explanations for the slit form of the cat's pupil have only been partially satisfactory, because, although explaining the slit, they could not explain its vertical direction.

This theory would be substantiated if it could be shown that an artificial slit-form pupil, even in the human eye, would increase the accuracy of indirect vision. With the object of making this test, experiments described in the following pages were carried out in the Psychological Laboratory of the University of Toronto.

The accuracy of the peripheral retina with regard to space perception presents three different aspects, which have to be

subjected to separate investigation. There is, first, the accuracy in distinction of discrete points; secondly, the accuracy with regard to the quantitative judgment of distances and differences of directions (angles) in the surface; and third, the accuracy with regard to perception of depth. Of these we, at present, only deal with the first.

The apparatus used in the experiments, which was devised by Dr. Kirschmann, consisted essentially of two parts, one bearing the object to be observed with an attachment for variation by the operator, the other representing an adjustable artificial slit-form pupil before the eye of the observer. The former (fig. 1) consisted chiefly of an instrument for the micrometrical mutual displacement of two bright objects (white squares of a diameter of 2 millimetres) on a dark background. This background was obtained by covering the instrument and its accessories, as well as the whole wall before which it was operated, with black velvet. (In the figure the velvet before the apparatus is removed.) By means of a universal joint and an adjustable rod to which the instrument was attached, it was possible to place it in any meridian and at any distance from the fixation point. The micrometer sledge with the plates bearing the objects could be rotated on an axis so that the line of separation and approximation could be placed at any angle to the meridian. The hand of the operator was hidden by velvet, so that the observer could not see anything but two white points on a very dark background.

The other essential part of the apparatus (the artificial pupil, fig. 2) was inserted into an aperture in a velvet-covered, solid, upright screen on a fixed table, before which the observer sat. This aperture was so shaped that it had a sharply outlined space for the nose of the observer, thus keeping the eyes in a fixed position without constraint. In this position the eye had directly before it the artificial pupil, which consisted of a fine slit adjustable both in width and direction. This slit was on a level with the fixation point and at a distance of one metre from it.

The method of operating was as follows. The eye of the observer was directed on the fixation point. The two points to

be observed in indirect vision, which were first in contact, were slowly separated by the micrometer screw. This movement was stopped when the observer gave the sign that he could distinguish the points as two. In the case of observer "K," readings were also taken at the point where the re-approaching points were no longer distinguishable as two. Observations were made at a distance of 10, 20 and 30 centimetres from the fixation point. These stand for the respective angles of 5° 43′, 11° 19′, and 16° 42′ (in the case of Table III, 21 Cm. or 11° 52′). Thanks are due to Professor Kirschmann for direction and advice throughout the investigation, and to Dr. F. H. Scott, Mr. J. L. Stewart, B.A., and Mr. W. H. Wood, B.A., for assistance in observations.

TABLE I—OBSERVER A.

Angular distance from Fixation-Point.	Number of Trials.	Without artificial Pupil.		Position of the Squares.	Position of the Slit.	Pupilar opening —3/32 of an inch.		Pupilar opening —2/32 of an inch.	
		Average Value.	m.v.			Average Value.	m.v.	Average Value.	m.v.
VERTICAL MERIDIAN UPWARDS.									
16° 42′	10	7.575	.57	. .	=	5.8	.56	5.175	.365
"	10			. .	‖	5.65	.30	5.077	.241
11° 19″	10	3.45	.35	. .	=	2.725	.135	2.325	.275
"	10			. .	‖	3.225	.275	2.55	.28
VERTICAL MERIDIAN DOWNWARDS.									
16° 42′	10	5.71	.35	. .	‖	4.425	.275	3.85	.28
11° 19′	10	4.15	.12	. .	=	2.05	.23	1.95	.17
"	10			. .	‖	2.625	.125	2.075	.12
HORIZONTAL MERIDIAN TO THE RIGHT.									
16° 42′	10	7.5	.7	. .	=	6.925	.24	4.825	.325
"	10			. .	‖	6.075	.255	5.6	.5
11° 19′	10	5.075	.34	. .	=	4.175	.51	3.475	.23
"				. .	‖	3.2	.29	2.275	.23
HORIZONTAL MERIDIAN TO THE LEFT.									
16° 42′	10	4.725	.195	. .	=	3.325	.24	3.125	.2
"	10			. .	‖	4.075	.365		
11° 19′	10	3.2	.39	. .	=	2.35	.27	2.1	.12
"	10			. .	‖	2.35	.22	1.95	.16

TABLE II—OBSERVER S.

Angular distance from Fixation Point.	Number of Trials.	Without Artificial Pupil.		Position of the Squares.	Direction of the Slit.	Pupilar opening —3/32 of an inch.		Pupilar opening —2/32 of an inch.	
		Average value.	m. v.			Average value.	m. v.	Average value.	m. v.
VERTICAL MERIDIAN UPWARDS.									
16° 42′	10	11.975	.472	. .	=	6.925	.157	5.75	.15
"	10			. .	‖	5.8	.26	4.95	.12
11° 19′	10	3.775	.365	. .	=	4.2	.244	3.75	.30
	10			. .	‖	3.3	.175	3.15	.17
VERTICAL MERIDIAN DOWNWARDS.									
16° 42′	10	5.08	.10	. .	‖	3.825	.109	3.3	.12
11° 19″	10	3.65	.11	. .	=	2.35	.115	1.95	.08
"	10			. .	‖	2.625	.13	2.075	.195
HORIZONTAL MERIDIAN TO THE RIGHT.									
16° 42′	10	8.575	.431	. .	=	8.175	.235	7.575	.229
"	10			. .	‖	7.25	.20	5.8	.12
11° 19′	10	5.0	.25	. .	=	3.925	.141	3.475	.23
"	10			. .	‖	2.75	.05	2.45	.095
HORIZONTAL MERIDIAN TO THE LEFT.									
16° 42°	10	4.675	.315	. .	=	3.65	.43	2.65	.15
"	10			. .	‖	2.9			
11° 19′	10	3.0	.10	. .	=	2.575	.19	2.1	.12
"	10			. .	‖	2.25	.15	1.825	.105

Table III

Angular distance from Fixation Point - 11° 52'

The values are the average of ten in case of Meridian of twenty readings

Meridian (45°)	Position of Rings (45°)	Direction of the Slit (45°)	Average minimum value of the distance of the points when seen diverse			
			Without artificial pupil	Width of the artificial pupil		
				$\frac{4}{32}$	$\frac{2}{32}$	$\frac{1}{32}$
Observer St.						
↙	∴	/	6.75	4.02	4.4	3.5
↖	∴	\	8.03	5.6	4.2	3.674
↗	∴	/	10.62	7.6	3.75	3.5
↘	∴	\	7.	5.37	4.8	3.92
Observer N.						
↙	∴	/	3.95	2.9	2.6	2.2
↖	∴	\	7.76	5.3	4.	3.29
↗	∴	/	8.2	6.7	4.3	4.2
↘	∴	\	4.1	3.7	3.1	2.9

Table IV. Observer K
Vertical Meridian. upwards

Angular Distance from Fixation Point	Number of readings	Position of diverse points	Without artificial Pupil			Direction of the Slit	With artificial Pupil					
							width $\frac{3}{32}$ of an inch			width $\frac{1}{32}$ of an inch		
			Δl	Δu	Δm		Δl	Δu	Δm	Δl	Δu	Δm
16°42'	20	▪▪	20.5	15.475	17.988	‖	10.1	6.175	8.138	8.375	4.79	6.583
11°19'	20	▪▪	12.45	9.3	10.875	‖	5.955	4.122	5.089	4.885	3.575	4.23
11°19'	20	▪	22.1	18.225	20.163	—	9.4	9.15	9.275	6.75	4.45	5.6
5°43'	20	▪▪	5.3	4.125	4.713	‖	4.1	2.6	3.35	2.8	1.1	1.95
"	20	▪	6.15	5.45	5.8	—	3.35	2.4	2.88	2.58	1.5	2.04
"	10	▪				‖	4.875	2.55	3.713	4.775	3.3	4.038
"	10	▪				\				3.975	2.975	3.475
"	10	▪				//	4.6	3	2.8			

Table V. Observer K
Horizontal Meridian. to the left

Angular Distance from Fixation Point	Number of readings	Position of diverse points	Without artificial Pupil			Direction of the Slit	With artificial Pupil					
							width $\frac{3}{32}$ of an inch			width $\frac{1}{32}$ of an inch		
			Δl	Δu	Δm		Δl	Δu	Δm	Δl	Δu	Δm
11°19'	20	▪▪	3.6	3.2	3.4	‖	3.076	1.6	2.388	2.53	0.58	1.56
"	10	▪▪				—	5.6	3.6	4.55	3.7	1.2	2.45
"	10	▪▪				\				3.68	1.28	2.48
"	10	▪▪				//	4.35	2.5	3.425			
"	10	▪	7.	4.225	5.613	\				3.1	1.8	2.45
"	10	▪				//	5.7	4.5	5.1			
"	20	▪				—	3.075	2.05	2.563	2.575	1.625	2.1
"	20	▪				‖	6.875	3.875	5.375	4.725	3.175	3.95

Table VI. Observer K
Oblique Meridian (45°) Downwards to the Right

Angular Distance from Fixation Point	Number of readings	Position of diverse points	Without artificial Pupil			Direction of the Slit	With artificial Pupil					
							width $\frac{3}{32}$ of an inch			width $\frac{1}{32}$ of an inch		
			Δl	Δu	Δm		Δl	Δu	Δm	Δl	Δu	Δm
11°19'	10	▪▪	6.	3.65	4.825	—	5.8	4.3	5.05	6.2	4.4	5.3
"	10	▪▪				‖	4.7	3	3.85	3.5	2.4	2.95
"	10	▪	14.33	10.42	12.38	‖	8.1	4.6	6.35	7.2	5.5	6.35
"	10	▪				—	7.	4.6	5.8	4.9	2.8	3.85
"	20	◆◆	7.65	6.95	7.3	\	7.4	6.8	7.1	4.55	3.55	4.05
"	20	◆◆				//	4.5	3.68	4.08	3.65	1.7	2.675

Our tables are almost self-explanatory. The average values and mean variations are given in terms of one whole revolution of the micrometer screw. Each such revolution is equivalent to a linear separation of 0.5 mm. of the discrete points. Our instruments, having been made in different countries, have measurements in different denominations, *i.e.*, the micrometer made in Europe has its gradation in millimetres, while the artificial pupil constructed in Toronto has its scale in inches. As the absolute values are of no importance in the present paper, they have not been reduced to a common denomination.

The 5th and 6th columns of Tables I and II, the 2nd and 3rd of Table III, and the 3rd and 7th of Tables IV, V and VI, indicate in a diagrammatic way the direction of the separation of the discrete points, and the direction of the slit of the pupil respectively. In Table III the direction of the oblique meridians is indicated by arrows. In Tables IV, V and VI, on account of the change in the method, we give for each series three values; $\triangle u$ designates the limit at which the approaching points were not further seen as two; $\triangle l$ designates the distance at which the separating points were first seen as two. There is always a considerable difference between these two values, which may, to a small extent, be due to the fact that the method of stopping the movement on a sign from the observer includes an error caused by a double reaction time. The greater part may be due to the knowledge of the condition, which will here act just in the opposite direction to the expectation in the ordinary method of least-observable difference. With approaching points we have the conscious, and with separating points the unconscious method. The average of the two values ($\triangle l$ and $\triangle u$) is indicated by $\triangle m$. The number of the readings refers to $\triangle m$. The mean variation, which for observer K was even smaller than for observers A and S, is omitted in Tables IV, V and VI. All space directions indicated graphically or otherwise in the tables refer to the vision field and not to the retina.

A glance at Tables I and II reveals the curious fact that the slit-form pupil,—no matter in what relation its direction stands to the position of the points to be distinguished—almost without exception, increases the accuracy of the distinction of discrete

points. Further, the decrease of the width of the artificial pupil conditions an increase in the accuracy of the distinction of discrete points, as is most consistently shown in Table III containing the results of experiments which were made by Messrs. J. L. Stewart, B.A., and W. H. Wood, B.A. In comparing these experiments with those of the other tables, it must not be forgotten that we employed here always the most favourable space relations between slit and separation of the points but not the most favourable with regard to the meridian. The results of Stewart and Wood also show distinctly the superiority of the lower half of the vision field. So far, these results, in themselves, are not conclusive in respect to the theory advanced regarding the cat's eye. The theory does not claim an advantage for a slit-form pupil as such, which, if its direction is irrelevant, does not act very differently from a decreased pupil, but it claims an advantage for a vertical slit when the points to be distinguished are situated in a horizontal direction. A close inspection of our tables, however, shows decidedly that the advantageous effect of the slit-form pupil is greatest when the slit is perpendicular to the direction of separation of the discrete points. Thus, for instance, in Table I, in the case of the horizontal meridian to the right, for a distance from the fixation point of 11° 19′, the distance necessary to let the two points appear as two, which had at the full opening of the pupil a value of 5.075 turns, decreases to 4.175 turns when the slit was 3-32 of an inch, and to 3.475 when the slit was 2-32 of an inch, but in both these cases the slit and the movements of the points were horizontal; when the slit was put in the vertical direction, the respective values were much further reduced, viz., to 3.2 and to 2.275 turns, respectively, and so throughout nearly all our results, at least for the horizontal meridian, where there is but one exception. The horizontal meridian, which is more important in our present paper, on account of the analogy with the conditions in the cat's eye, has besides for all living beings the greatest significance. A partial exception might be assumed for birds and animals living in trees.

The vertical meridian presents in our trials a considerable difficulty, for we find that a considerable number of exceptions

occur. There are cases where a slit in a direction other than vertical to the line of separation was just as good or even better than the vertical one, but this may be due to the fact that another factor enters here, viz., the relation of the direction of the slit to the meridian. Unfortunately in the trials with observers A and S we had not realized this fact, always using the objects in the horizontal position. It might be that the advantage, which the position vertical to the direction of the movement gives, is counterbalanced by the disadvantage when the slit is not perpendicular to the meridian. It might also be that the horizontal direction has some advantage throughout the whole vision field. The trials in the vertical meridian by observers A and S are not conclusive, because they were made with regard only to the relation of the position of objects to the direction of the slit, whilst the significance of the direction of the eye-movement of greatest facility (in the meridian) was neglected. In this case there will be an antagonism between two variables whose maxima do not coincide. In the experiments of observer K, we tried to avoid this error by using also, at least for the smaller distances from the fixation point, the vertical position of the points. It can be plainly seen that a slit perpendicular to the line of separation is more favourable than one in any other direction, and that the most favourable case is that in which, in addition, the line of separation coincides with the meridian. This is especially clear in the case of the oblique meridian (Table VI), where we find for the most favourable conditions just mentioned (marked by an asterisk in Tables IV, V and VI) a minimum of 2.675 in observations through the narrower slit, whilst the greatest values, viz., 5.3 and 6.35, occur quite correctly according to our theory when the most unfavourable conditions obtain, viz., that the slit is parallel to the line of separation and the latter does not coincide with the meridian.

In conclusion, we may enumerate what our experiments seem to prove.

(1) A slit-form pupil aids in the distinction of discrete points, as indeed might be expected from any contracted pupil, but it does not give equal advantages in all directions.

(2) A slit-form pupil is of great value in the distinction of discrete points for a direction perpendicular to the slit of the pupil. The accuracy increases with the decrease of the width of the slit.

(3) The most favourable conditions for the effectiveness of the slit-form pupil are realized when not only the slit of the pupil is perpendicular to the line on which the discrete points are situated, but when also this line coincides with a meridian of the eye.

(4) In the human eye the maximal keenness in distinction of discrete points obtainable by an artificial slit-form pupil is found in the horizontal meridian. It is very likely that this preference of the horizontal meridian would be found in a still higher degree with smaller animals (*e.g.* the cat), whose interest is concentrated on the horizontal plane, and whose eyes are constantly provided by nature with a pupil contractable to a vertical slit.

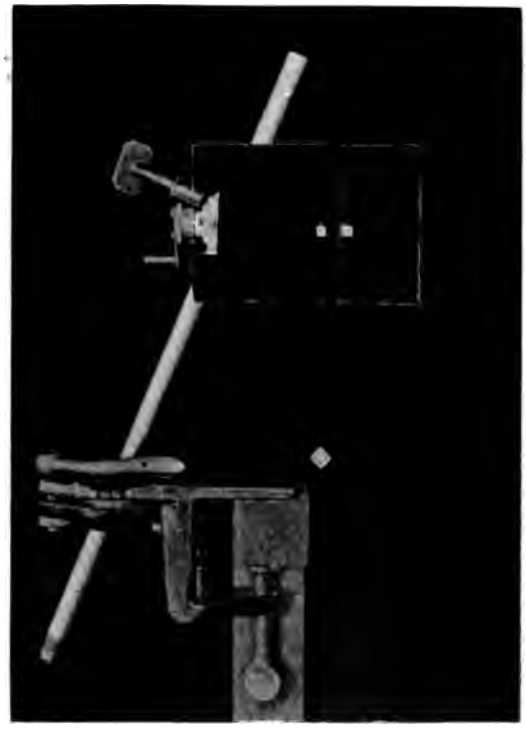


FIGURE 1

U of M

FIGURE 2

U of M

EXPERIMENTS ON THE AESTHETICS OF LIGHT AND COLOUR

THIRD ARTICLE

COMBINATIONS OF COLOURS AND UNCOLOURED LIGHT

BY

SUSIE A. CHOWN, B.A.

COMBINATIONS OF COLOURS AND UNCOLOURED LIGHT

That the aesthetic value of colour is occupying more largely than ever before the minds of various classes of people can not be gainsaid. Not infrequently nowadays articles are published in magazines dealing with the effect of colour in some one of its different phases. In France recently tests were made in an insane asylum as to the effect of colour upon the inmates. It was found that a person violently insane was immediately quieted by being taken into a blue or violet room. Experts maintain that the decorations and draperies of living rooms have more or less effect upon the physical and mental health of the occupants. Whatever truth there may be in these statements, they at least show that the thoughts of more than one class of people are turned in the direction of emotional colour effects.

This should not be at all surprising since we know that the hedonic characters of the colour qualities are widely different. Not for bulls and turkeys, children and savages only, is red the most exciting colour, but it is so for grown up and highly educated people also, even if they show no outward signs of it. In the same way green is the most indifferent and blue the coldest and most tranquilizing colour; whilst in the purple and violet the cooling and quieting effect of the blue and the animating effect of the red combine to give the character of a grave and superior though somewhat uneasy dignity.[1] It is no mere whim then that makes us use green lampshades and decorations in our studies where we wish to give the mind the ease and rest necessary for concentrated work, whilst we prefer in our dining-rooms red wall papers on account of the animating and appetizing effect of this colour; nor is it merely accidental that a certain reddish purple is the colour of royalty and violet the episcopal colour. Æsthetically the colours between red and purple are extremely exclusive, so much so that almost nothing will harmonize with them except gold.

[1] Wundt, *Physiological Psychology*, Fifth Edition, vol. II., p. 323.

That these things have, in practice, to be tried empirically is largely due to the fact that the popular ideas of colours in their variabilities are inadequate and unscientific and that the usual nomenclature is not only very incomplete but in many cases absolutely illogical. The scientific nomenclature is too simple; for all the qualities between green and blue we have no other designation than blue-green, green-blue, bluish-green, etc. On the other hand the names used in commerce are almost too numerous. Certainly they are inconsistent in so far as the "colour" does not refer only to the light impression, but very often also to the texture and other qualities of the material. This is so with regard to intensities; we call the slate of a blackboard "black," though it is scarcely as dark as some medium grey papers; if it is slate it is black; while if it is paper it is grey. We speak of black cloth, but a piece of silk or velvet which shows exactly the same intensity and light quality is called not black but grey; these materials in order to be termed black must be very much darker than cloth. Some of the colour designations can be applied only to material which has a lustre, such as silk and satin, others are dependent on the nature, roughness, or grain of the texture; others again refer only to reflected light, never to luminous bodies.

Gladstone and some German scientists once advocated the theory that the ancient Hebrews and ancient Greeks had not the fully developed colour-sense, and especially did not perceive blue and violet. This inference was drawn from the seeming poverty of the Greek and Semitic languages in regard to colour designations. Some hundreds of years hence it may be that our successors will not be able to understand how the colour terminology of our own day could have been arrived at, and how people could speak of red hair and tan shoes or ignore the difference in the light-quality of snow and the complexion of part of the human race, both of which are called white. But these are only comparatively insignificant examples of the inconsistency of our present nomenclature of

light qualities. The greatest mistake made is that of mixing up saturation, intensity and colour-quality.[1] Magenta, rose and pink are regarded as different colour-qualities though they are only different tints of the same colour—a purplish red. They differ, apart from slight variations in colour-tone which do not appear in their names, only in saturation and intensity. In a similar way scarlet, cardinal and crimson are to be regarded as shades of red rather than as different qualities; by crimson is sometimes meant a blood-red, sometimes a royal purple. Cream is really a very light tint of orange. The so-called tertiary colours which usually go under special names such as olive, russet, pearl, etc., and are regarded as new colours resulting from the mixture of the secondary colours, are in reality nothing but ordinary colour-qualities with reduced saturation; thus if a greenish yellow is mixed with a colourless light of a certain low intensity the result is olive. Similarly if the saturation of orange (or reddish orange) is reduced by mixing with it much colourless light of the same intensity russet is obtained. As Dr. Kirschmann says: All these obsolete ideas of primary, secondary and tertiary colours are based on laws about colour mixture which were once approximately correct, when the decorative art had at its disposal only a few mineral colours of great purity, but which are, in the light of modern colour-chemistry, absolutely incorrect. There was once a time when the painter could say that a pure red could not be gained by the mixing of pigments; there was then no finer red than the mineral vermilion and the animal colour carmine, or the stained layer of the ruby glass coloured with cuprous oxide and traces of a certain gold compound. In our day, however, the most beautiful and spectrally the purest red which can be produced is the mixture of two aniline colours, an orange-yellow and a violetish-blue.

For some particular purpose a colour is given a certain name; the public is unable to distinguish between the name and

[1] Kirschmann, *Conceptions and Laws in Aesthetics.* (Univ. of Toronto Studies, Psych. Series, vol. I, p. 199.)

the original colour and so takes it for granted that this new name implies a new colour. Only a few names of colours are original (going back to Aryan roots); red, yellow, green and blue may be so classed, but even these names may have referred to some objects at first. All other names of colours are derived from names—

1st, *of fruits or other food:* orange, pea-green, cherry, strawberry, pistache, lemon yellow, olive, maroon, apple green, corn, café-au-lait, cream, melon;

2nd, *of flowers:* violet, pink, rose, heliotrope, wisteria, mauve, yucca, dahlia, primrose yellow, lilac, ivy, mignonette, grenat, moss rose, moss green;

3rd, *of other vegetable substances:* straw, sage, hazel (used only for women's eyes);

4th, *of metals:* gold yellow, steel blue, steel grey, red lead, copper red, zinc white, pepita (Spanish for nugget of gold);

5th, *of precious stones:* jasper, emerald, sapphire, turquoise, garnet, ruby, malachite, azure (lazur—lapis lazuli), pearl grey, pearl blue;

6th, *of other mineral substances:* terra di sienna, terra cotta, chrome yellow, chrome orange, terra verte, cobalt blue, mineral grey, umber, ochre;

7th, *of animals and animal substances:* sepia, crocodile, titiens (Antillean Warbler), fawn, ibis, llama, ivory black, canary yellow, robin's egg blue, elephant green, seal brown, dove, salmon, chamois;

8th, *of proper names—persons:* Bismarck (orange brown), Jean Bart (dark blue), Van Dyck brown, Van Dyck red, Rembrandt (red), Davy's grey, Payne's grey, Ophelia, Sappho, Victoria green;

9th, *of proper names—places:—*

(a) *countries and districts*—Gamboge, Quito, Egyptian, Labrador, Havana, Siam, Palestine (dull pink), Sauterne, African green, Helvetia, Magenta;

(b) *nations or tribes*—Italian pink, Judee, Zulu, Prussian blue, Chinese white;

(c) *cities, rivers or towns*—Nyanza (pale yellow green), Muscovite (sage-green), Naples yellow, Venetian red, Paris green, Solferino, Mablo yellow, Yale;

10th, *of other names*: Cossack (dark yellow green), mandarin, évêque;

11th, *of miscellaneous sources:* dragon's blood, lamp black, sea-green, khaki brown, ultramarine, nankeen, neutral tint, permanent white, mascot (very dark blue) (Fr. mascotte—witch);

12th, *of mythological characters:* Mars orange, Mars yellow, Pygmalion, Hebe.

This list is sufficiently extensive for our purpose but it is by no means exhaustive, nor is this variety of nomenclature likely to decrease.

The reason why up to this time there is no reliable source of information on colour æsthetics is that the multitudinous possibilities in colour combinations have not been taken into account.[1] Æsthetical laws have to be found empirically; mathematical deduction is only conditionally applicable and even then within very narrow limits. Investigation with the purpose of ascertaining empirically æsthetical laws has only begun, and the enormous task is still before us. The only experimental works on colour combinations are those of Jonas Cohn and Miss Baker, of which the latter seems the more important since Cohn has worked with too small a number of qualities and apparently relied with regard to complementarism simply on conventional statements. Both worked on binary combinations; Miss Baker's work refers to the colours in full saturation only and thus treats of a side of the question which, though fundamental, is not of great importance with regard to practical application; for it is scarcely ever binary combinations of highly saturated colours which we use for architecture, decoration or dress. The colours used for the purposes thus stated are mostly the so-called broken colours with here and there an interspersion of a

[1] Kirschmann, *Conceptions and Laws in Aesthetics* (Univ. of Toronto Studies, Psych. Series, vol. I, p. 200).

saturated colour. The so-called broken colours, however are nothing else than colours in diminished saturation and sometimes perhaps with changed light intensity. In other words, for practical purposes we seldom have to deal with fully saturated colours, but usually with shades and tints. Further, not only the qualities of the chromatic series are used for æsthetic purposes but also colourless light in its many variations of intensity. It is just the combinations of colourless light on the one side and the colours in their different saturation-degrees on the other which we have made the subject of an investigation, the results of which are unfolded in the following pages. These experiments were carried on during the academic terms of 1901, 1902 and 1903 in the psychological laboratory of the University of Toronto under the direction of Professor Kirschmann.

The Prang colours in full saturation which Miss Baker used, and also the second shades and second tints of the same, were employed in these experiments. The room and apparatus were the same as those used by Miss Baker and described in her first article.[1] As representatives of the achromatic light the five greys of the Prang standard colour papers and the white and black of the Milton Bradley educational papers were used. They thus formed a series of seven intensities of uncoloured light. Unfortunately we can not claim that the intervals between them are of equal value. The distance between the darkest Prang grey and the Milton Bradley black seems to be greater than that between that grey and the next brighter one, though this discrepancy is somewhat mitigated by the darker background of black velvet which made the black paper appear only as a dark grey. A similar discrepancy is found at the other end of the series, the interval between the white and lightest grey appearing to be greater than that between the greys themselves.

Our method was the same as that of Miss Baker, the so-called "method of selection in serial comparison." When the colours

[1] University of Toronto Studies, Psych. Series, vol. I, pp. 205 etc.

of full saturation were used, two variations of the method were employed; at one time the twenty-four colours were constant (i.e., remained on the table) and the greys varied, and at another the greys were constant and the colours varied. In the one case the observer had the choice among twenty-four and in the other case among seven combinations; with the tints and shades, however, no such chance was given, the choice always being from the twenty-four.

All observations were made in the early hours of the afternoon, in a large room (the old Ethnological museum) which is lighted by a skylight almost the size of the whole ceiling, and is thus provided with most favourable illumination. There were twelve observers, but in the following record only the results from eight of them are given; these, however, completed the following series twice:—

1st. A comparison of the combinations of fully saturated colours and greys—

(*a*) Greys constant,

(*b*) Colours constant.

2nd. A comparison of combinations of tints and greys—tints always constant.

3rd. A comparison of combinations of shades and greys—shades always constant.

Duplication was necessary in order to secure some criterion for the consistency of the observers' judgments.

The fully-saturated colours were designated by the numbers one to twenty-four as in Miss Baker's article.[1] In the case of tints the numbers had the index t, in the case of shades the index s. Thus 7 means yellow orange in the fully-saturated colours, 7t means the second (according to Prang) tint of this colour, and 7s similarly the second shade. The members of the achromatic series were designated by the numbers one to seven, black being one and white seven. The intensities of the different greys, according to photometrical measurements reported elsewhere in this number by Mr. Smith,[2] are as follows:—

[1] Univ. of Toronto Studies, Psych. Series, I, 221.

[2] *Infra*, p. 36

	Illumination by Auer-Light	Illumination by Daylight
Milton Bradley's Black	1.	1.
Prang's darker grey	2.667	4.261
Prang's dark grey	3.507	4.933
Prang's grey	4.728	6.467
Prang's light grey	8.116	9.916
Prang's lighter grey	11.902	17.202
Milton Bradley's White	40.620	43.074

In all the following tables the first vertical column gives the numbers of the colours within the manifoldness of twenty-four. Each of the series of achromatic light is represented by a vertical partition comprising three columns. The first contains the number of cases in which that combination of the colour and the achromatic sensation was selected as pleasant, the second gives the number of cases for the selection as most pleasant, and the last column the number of unpleasant cases.

Tables I, II, and III which are directly comparable, refer to the combinations of greys with the colours in full saturation, with tints and with shades; the colours were always constant. In Table IV the seven greys were constant and the colours changed; this necessitated a selection out of seven instead of twenty-four, and thus the results cannot be directly compared with the results of tints and shades, especially since never more than one quality was exposed to the view of the observer at one time. Finally, in Table V, the results of Tables I and IV are combined.

Since tables containing so many numbers are not very perspicuous and cannot give at a glance any adequate conception of the result of our work, it was thought advisable to illustrate by curves which are more easily surveyed. Plates I to IX are intended to fulfil this requirement. Each of the Plates I to VII graphically represents the results for one of the degrees of intensities of the achromatic light, the lower figure always refers to shades, the middle one to the colours, and the upper to the tints. There are in each figure two curves, the upper one representing the "pleasant," the lower one the "most pleasant" judgments. On the abscissa line are repre-

sented the twenty-four qualities, and the length of the ordinates corresponds to the number of judgments.

In Plate I the combinations with black are represented. Two maxima in the "pleasant" as well as in the "most pleasant" curves are very conspicuous, the one is in red (No. 2) and the other in blue (No. 17); these appear more decided, i.e., the curves are more pointed and higher in shades than in colours and much more so than in tints. It may be noticed also that the maxima of the "most pleasant," here as throughout the whole series of curves, are highest in the shades and lowest in the tints, but that if the area of the curve is considered a different result is given. (The numerical value of these areas is indicated by the sums given at the foot of the vertical columns in our tables.) The area of the "pleasant" curve is greater for the full colours than for shades and still greater for tints. It may be mentioned here that the "pleasant" and "most pleasant" curves sometimes meet but never intersect, the highest ordinate always denoting the pleasant. The rest of the curves show a very similar behaviour; the two maxima at two or three and at seventeen, eighteen and nineteen are visible in all the curves; this indicates that at least for the colours used in this experiment there is a maximum of pleasantness in combinations with grey for red and blue. The blue in question is by no means complementary to the red. It may be interesting to note the fact that blue and red were found to be complementary in a case of monocular colour-blindness described by Kirschmann[1], and that Dr. Lane[2] showed that the most favourable condition with regard to the space threshold exists not between complementaries but between red and blue.

The question may be asked, what is the cause of the decided advantage which the red and blue have? It might be said that this is a peculiar property of the Prang colours, that the red, blue and violet are especially saturated or especially mild. But a close examination of the colours with regard to

[1] Philosoph. Studien, vol. VIII, pp. 198 etc.

[2] University of Toronto Studies, Psychol. Series, vol. I, p. 87.

these properties contradicts the assumption. There is also no direct connection visible between these two maxima and the points of the colour-circle (Prang's colours so arranged) which show characteristic behaviour with regard to complementarism[1]. On the other hand it is very remarkable that the maximal points of pleasantness in combinations with grey correspond more or less accurately with the minimum points in Miss Baker's combination curve. There the yellows and yellow-greens are chosen most frequently in combination with other colours and our results show that they are chosen less frequently with grey (uncoloured) light. Thus it seems to be established that *the greater the possibility for a certain colour to please in combination with other colours, the less likely is it to please in combination with grey.*

A rather unexpected but none the less welcome outcome of our results is that we are now able to trace the origin of the often repeated and never experimentally confirmed belief that there is in some persons, or in all, a certain aversion to yellow. Reichenbach held that such aversion was found chiefly in persons sensitive to the "od." Miss Baker in discussing the question seems to attribute this aversion, if existing at all, to the "associative factor." There can be no doubt that this factor, the aversion to certain objects which are yellow, may play a prominent rôle but does not offer the solution. Yellow was in Miss Baker's trials the colour most frequently chosen; in our results yellow and green are plainly in the minimum. What does this indicate? Perhaps yellow and green are preferable in combination with other colours because they are the most indifferent, emotionally, thus furnishing in such combination a considerable contrast with regard to the hedonic tone. This same quality of comparative indifference makes them least apt when combined with indifferent grey because there is not enough variety in the hedonic tone. If we consider now the greys and those broken colours which approach grey, and are so largely used

[1] *Infra*, p. 23 etc.

for clothing and furniture, we can understand how people can come to the conclusion that yellow is to a greater or less extent unpleasing; *it does not suit the grey and greyish tints of our surroundings as well as red or blue.* For some amount of contrast seems to be requisite for the production of a high æsthetic effect, be it the contrast of colour-qualities, of saturation, of intensities, or of the hedonic tones.

Of the two minima which our curves show, the one in the yellow and green is more decided and more definitely placed than that in the purple. The depression of the "pleasant" curve throughout is far deeper in the yellow-green than in the purple; and in comparing the curves it will be easily noticed that the gap covering the middle of the spectrum is widest in the curves for shades and narrowest in those for tints. It may also be observed that in combination with black and the darker greys the maximum in red has a slight advantage over that in blue, whilst in the combination with the lighter greys and white—especially for the tints—the maximum in blue has the superiority.

It is quite characteristic that though the maxima are not considerably higher in tints than in shades, yet the forms of the curves show marked differences. The rising of the curves near the maximal points is steeper and more abrupt for the shades; whilst the colours and still more the tints, especially for the maximum at red, show a certain rounding off. This is visible in all curves, but the higher the intensities of the greys the less marked this difference becomes. The minima of the curves are not quite as uniform as the maxima though they are always to be found in the yellow, green and purple; with the increase of the intensity of the grey the minimum regions seem to broaden somewhat and also to shift toward the right, i.e., from the yellow to the green.

In regard to the area which the curves enclose and which is an exact measure of the capacity for harmony of the grey in question, we may refer back again to our tables. The numbers at the bottom of the columns are representative of these areas and the number designated "Gr. T." gives always the

grand total for the whole table. From these numbers we see plainly that for the shades as well as for the colours and the tints there is a marked growth in the capacity for harmony with the increase of intensity, i.e., the totals always progress from black to white. Throughout the whole of the tables we see that combinations with brighter greys and white are more favoured than those with the darker grey and black. From the numbers representing the grand totals we see again that the combinations of greys with tints have an advantage over those with full saturation and these over those with shades.

The total number of "pleasant-decisions" is 1189 for the shades, 1342 for the colours, and 1695 for tints; the corresponding numbers for the "most pleasant decision" are 210 for shades, 235 for colours, and 240 for tints. The tables give also in the last division the totals for the colour-qualities; the curves show throughout such uniform features that these numbers can only indicate on an enlarged scale what each curve shows for itself, viz., the superiority of the red and blue and the inferiority of the yellow and purple. Consequently the totality curves given in Plates VIII and IX are very similar to the curves in the other plates.

As we have stated above, the experiments with the colours of full saturation were carried on in two ways; in the one case the colours were varied and in the other the greys. Since we have here a selection from twenty-four on the one hand and only seven on the other, the two sets cannot well be compared. Table IV gives the results of the experiments where the greys were constant, and in Table V the total for the colours in full saturation is given, confirming the results of Table I with regard to the colours but not altogether with regard to the greys, for the minimum of pleasantness seems to lie with the medium greys and not with the black. Corresponding to Table V we have drawn the curves in Plates X and XI, of which the former refers to the "pleasant" and the latter to the "most pleasant" combinations. In order to gain space we let the areas of the curves overlap to some extent; to facilit-

ate the understanding of the curves the designations Black, Grey I, Grey II, etc. are attached not only to the curves but also to the places of their respective abscissa-lines. These curves again show plainly the maxima for the colours two and seventeen and eighteen, a great minimum for the yellow-greens and a somewhat smaller depression for the violet purple. The greatest area is to be found in the white and the smallest in the medium grey.

Summary

I. In combinations of a coloured and an uncoloured surface, of equal shape and size, the more emotional colours, i.e., the so-called warm and cold colours have æsthetically a decided advantage. The best æsthetic effect is obtained with red and with blue.

II. Tints seem to harmonize more easily with colourless light than colours in full saturation, and these more easily than shades. Nevertheless, the effect of greatest pleasantness is mostly obtained with full colours and shades. (See "most pleasant" curves.)

III. The emotionally indifferent colours, yellow, yellow-green and green, and to a lesser degree violet and purple also, furnish with uncoloured light indifferent or even unpleasant combinations; and the more so, the less light intensity the components show.

IV. The much discussed but experimentally never verified assumption of the aversion to yellow probably has its foundation in the fact that yellow does not harmonize easily with colourless light.

TABLE I.—COLOURS IN FULL SATURATION, COLOURS CONSTANT

Number of Colour	Black			Grey I.			Grey II.			Grey III.			Grey IV.			Grey V.			White			Total	
	Pleasant	Most Pleasant	Unpleasant	Pleasant	Most Pleasant	Unpleasant	Pleasant	Most Pleasant	Unpleasant	Pleasant	Most Pleasant	Unpleasant	Pleasant	Most Pleasant	Unpleasant	Pleasant	Most Pleasant	Unpleasant	Pleasant	Most Pleasant	Unpleasant	Pleasant	Most Pleasant
1	14	4	0	10	0	..	12	3	..	7	1	..	12	1	..	14	5	..	12	4	..	81	18
2	15	5	..	15	4	..	16	9	..	16	5	..	16	5	..	16	6	..	16	7	..	110	41
3	14	2	..	14	3	..	13	2	..	16	3	..	14	3	..	15	4	..	14	4	..	100	21
4	11	1	..	10	1	..	10	0	..	13	0	..	10	0	..	11	0	..	12	0	..	77	2
5	10	0	..	10	0	..	9	0	..	10	0	..	9	0	..	7	0	..	10	0	..	65	0
6	8	2	..	9	2	..	8	3	..	9	0	..	10	2	..	9	0	..	11	0	..	64	9
7	9	1	..	9	1	..	8	2	..	7	1	..	10	0	..	5	0	..	10	1	..	58	6
8	8	1	..	10	3	..	8	1	..	5	2	..	9	3		5	1	..	7	2	..	52	13
9	4	1	..	4	0	..	2	2	..	4	0	..	6	0	..	3	3	..	5	0	..	28	6
10	2	0	..	1	0	..	2	0	..	1	1	..	5	1	..	4	0	..	5	0	..	20	2
11	0	0	..	3	0	..	1	0	..	0	0	..	2	0	..	5	0	..	5	0	..	16	0
12	2	0	..	4	1	..	3	0	..	4	1	..	2	0	..	4	0	..	6	0	..	25	2
13	4	0	..	3	0	..	3	0	..	2	0	..	2	0	..	6	0	..	5	1	..	25	1
14	2	0	..	2	0	..	3	1	..	2	0	..	4	2	..	4	0	..	6	0	..	23	3
15	2	0	..	1	0	..	3	0	..	3	0	..	3	0	..	5	1	..	6	0	..	23	1
16	8	0	..	7	2	..	9	1	..	12	1	..	11	0	..	12	2	..	10	2	..	69	8
17	13	8	..	14	7	..	14	4	..	15	7	..	15	6	..	16	8	..	13	9	..	100	49
18	11	0	..	13	2	..	10	2	..	15	4	..	15	6	..	14	2	..	14	2	..	92	18
19	7	3	..	10	0	..	7	2	..	10	3	..	11	2	..	9	2	..	8	0	..	62	12
20	7	0	..	9	0	..	8	2	..	8	0	..	8	1	..	9	1	..	7	1	..	56	5
21	6	0	..	7	0	..	7	1	..	8	2	..	8	1	..	10	1	..	10	1	..	56	6
22	4	0	..	4	1	..	8	1	..	7	0	..	5	0	..	9	1	..	7	0	..	44	3
23	5	0	..	5	2	..	7	1	..	6	0	..	9	0	..	10	1	..	9	2	..	49	6
24	6	1	..	5	0	..	8	0	..	6	1	..	6	1	..	7	0	..	10	0	..	48	3
Total	172	29		179	29		179	37		186	32		200	34		209	38		218	36		1343	235

Grand Total—1343 Pleasant; 235 Most Pleasant.

TABLE II.—TINTS.

Number of Colour	Black			Grey I.			Grey II.			Grey III.			Grey IV.			Grey V.			White			Total		
	Pleasant	Most Pleasant	Unpleasant	Pleasant	Most Pleasant	Unpleasant	Pleasant	Most Pleasant	Unpleasant	Pleasant	Most Pleasant	Unpleasant	Pleasant	Most Pleasant	Unpleasant	Pleasant	Most Pleasant	Unpleasant	Pleasant	Most Pleasant	Unpleasant	Pleasant	Most Pleasant	Unpleasant
1	12	0	..	10	0	..	13	1	..	14	0	1	15	0	..	12	0	..	13	0	..	89	1	1
2	15	2	..	13	1	..	16	3	..	16	1	..	16	1	..	14	2	..	13	1	..	103	11	..
3	16	4	..	16	4	..	16	4	..	16	2	..	16	2	..	15	1	..	15	2	..	110	19	..
4	14	2	..	13	0	..	15	0	..	12	0	..	16	1	..	12	1	..	15	0	..	97	4	..
5	15	2	2	12	0	2	15	1	2	13	0	..	11	0	..	12	1	..	12	0	..	90	4	6
6	14	1	2	10	1	2	12	3	2	12	1	2	12	1	1	13	1	..	12	1	..	85	9	9
7	12	2	2	9	1	2	10	1	2	12	0	2	11	0	1	11	0	..	12	0	..	77	4	9
8	11	2	2	8	0	2	7	0	2	10	0	3	10	0	1	12	1	..	14	0	..	72	3	10
9	5	2	2	7	4	2	6	4	2	9	2	2	7	3	1	9	3	1	7	3	..	50	21	10
10	2	0	2	5	0	2	4	1	1	4	0	2	4	0	1	7	2	..	7	1	..	33	4	8
11	3	0	2	4	1	1	4	0	2	3	0	..	6	0	1	5	0	..	6	0	..	31	1	6
12	3	0	1	1	0	1	1	0	..	3	0	1	4	0	..	4	0	..	4	0	..	20	0	3
13	5	0	..	0	0	..	4	0	1	2	0	..	3	0	1	9	0	..	9	0	..	32	0	2
14	6	0	..	3	0	..	4	0	1	2	0	..	4	0	..	9	0	..	8	0	..	36	0	1
15	7	0	..	5	1	..	7	0	..	8	0	..	4	0	..	9	0	..	7	0	..	47	1	..
16	10	0	..	9	2	..	8	2	..	12	2	..	9	2	..	13	3	..	11	2	..	72	13	..
17	14	4	..	14	3	..	15	4	..	16	8	..	19	5	..	19	6	..	20	8	..	117	38	..
18	12	5	..	14	4	..	15	3	..	18	3	..	16	2	..	17	4	..	18	5	..	110	26	..
19	12	2	..	9	1	..	11	3	..	13	2	..	12	2	..	14	5	..	13	5	..	84	20	..
20	8	1	..	8	2	..	8	1	..	9	1	..	8	3	..	9	0	..	10	1	..	60	9	..
21	9	3	1	11	1	1	11	3	1	9	4	..	9	4	1	13	3	..	15	2	..	77	20	4
22	7	1	..	9	0	1	11	0	..	11	1	..	12	3	1	12	0	..	11	2	..	73	7	2
23	8	1	..	10	3	..	9	1	..	9	4	..	11	5	1	10	4	..	11	3	..	68	21	1
24	8	0	..	8	0	..	8	0	..	9	2	..	8	1	..	11	0	..	10	1	..	62	4	..
Total	228	34	16	208	29	16	230	35	16	242	33	13	243	35	10	271	37	1	273	37		1695	240	72

Grand Total—1695 Pleasant; 240 Most Pleasant; 72 Unpleasant.

TABLE III.—SHADES.

Number of Colour.	Black			Grey I.			Grey II.			Grey III.			Grey IV.			Grey V.			White			Total		
	Pleasant	Most Pleasant	Unpleasant	Pleasant	Most Pleasant	Unpleasant	Pleasant	Most Pleasant	Unpleasant	Pleasant	Most Pleasant	Unpleasant	Pleasant	Most Pleasant	Unpleasant	Pleasant	Most Pleasant	Unpleasant	Pleasant	Most Pleasant	Unpleasant	Pleasant.	Most Pleasant.	Unpleasant.
1	7	1	1	10	..	..	10	..	..	9	..	..	12	1	..	11	..	..	10	..	..	69	2	1
2	16	8	..	16	9	..	18	9	..	17	6	..	18	7	..	11	7	..	18	10	..	114	56	..
3	9	1	1	11	1	..	13	2	..	10	1	..	12	3	..	13	..	..	14	..	..	82	8	1
4	8	..	1	6	..	..	8	1	..	6	..	..	8	..	..	8	..	..	9	..	..	53	1	1
5	3	..	1	3	..	..	2	1	..	3	..	..	2	..	..	3	1	..	7	..	..	23	2	1
6	4	1	1	3	..	..	3	..	..	2	..	..	3	..	..	3	..	..	4	..	..	22	1	1
7	3	..	1	3	..	..	2	..	2	1	..	1	3	..	..	3	..	1	2	..	1	17	..	6
8	3	..	1	3	..	..	3	..	2	2	..	1	3	..	..	3	..	1	2	..	1	19	..	6
9	5	2	2	5	..	..	5	1	3	4	..	2	5	1	4	5	..	2	5	..	2	34	4	15
10	2	..	3	3	..	..	3	..	3	3	1	4	3	..	2	3	1	3	4	..	2	21	2	17
11	..	..	2	2	..	..	..	..	2	2	..	1	2	..	2	..	..	3	2	..	1	8	..	11
12	1	..	2	2	..	..	3	..	..	3	..	..	4	..	1	2	..	2	5	..	1	20	..	6
13	5	..	1	3	..	1	2	..	2	5	..	..	6	..	..	6	..	1	6	..	1	33	..	6
14	4	..	2	4	..	1	3	..	1	5	..	..	6	..	..	4	..	1	7	1	1	39	1	6
15	2	..	1	3	..	..	5	..	..	5	..	..	7	..	..	6	..	1	6	..	1	34	..	3
16	10	..	..	12	..	..	12	2	..	12	..	..	13	..	..	14	..	1	12	..	1	85	2	2
17	16	8	..	17	9	..	17	9	..	16	10	..	17	10	..	16	9	..	17	9	..	118	64	..
18	11	8	..	12	4	..	13	2	..	11	5	..	14	4	..	14	6	..	15	8	..	90	37	..
19	11	2	..	12	2	..	12	3	..	13	1	..	13	2	..	11	3	..	12	1	..	74	14	..
20	4	..	..	7	..	..	7	..	..	9	1	..	8	..	..	10	..	..	8	..	..	53	1	..
21	5	..	..	7	..	..	8	2	..	8	3	..	9	2	..	9	3	..	9	2	..	54	12	..
22	1	..	..	5	..	..	5	..	..	5	..	..	6	..	..	7	..	..	5	..	..	34	..	..
23	4	..	1	8	1	..	6	1	..	8	1	..	9	..	..	9	..	..	7	..	..	45	3	1
24	5	..	1	7	..	..	7	..	1	7	..	..	7	..	..	8	..	..	7	..	..	48	..	2
Total	139	31	22	164	26	2	167	33	16	166	29	9	190	30	9	170	30	16	193	31	12	1189	210	86

Grand Total : 1189 Pleasant, 210 Most Pleasant, 86 Unpleasant.

TABLE IV.—COLOURS, GREYS CONSTANT.

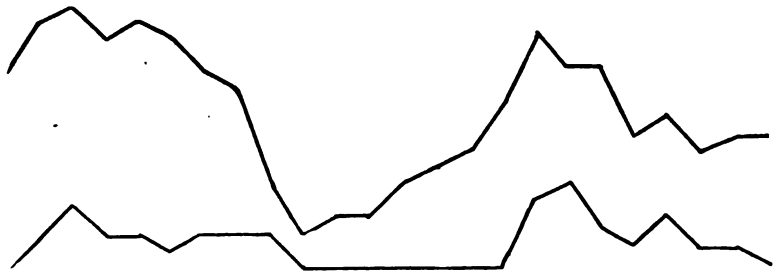
Number of Colour	Black			Grey I.			Grey II.			Grey III.			Grey IV.			Grey V.			White			Total	
	Pleasant	Most Pleasant	Unpleasant	Pleasant	Most Pleasant	Unpleasant	Pleasant	Most Pleasant	Unpleasant	Pleasant	Most Pleasant	Unpleasant	Pleasant	Most Pleasant	Unpleasant	Pleasant	Most Pleasant	Unpleasant	Pleasant	Most Pleasant	Unpleasant	Pleasant	Most Pleasant
1	10	3	..	12	3	..	9	2	..	7	1	..	11	2	..	12	5	..	14	10	..	75	26
2	11	4	..	10	2	..	9	..	..	9	..	..	11	..	..	14	5	..	13	13	..	77	24
3	10	4	..	7	2	..	8	1	..	7	..	..	10	2	..	13	4	..	15	9	..	70	22
4	9	4	..	7	2	..	8	1	..	6	..	..	9	3	..	9	3	..	13	8	..	61	21
5	7	4	..	9	1	..	10	3	..	9	2	..	8	1	..	8	4	..	10	5	..	61	20
6	11	6	..	7	2	..	7	1	..	9	..	..	10	1	..	12	2	..	14	11	..	70	23
7	11	5	..	7	1	..	5	1	..	5	..	..	9	1	..	10	3	..	15	8	..	62	19
8	8	7	..	8	2	..	8	..	..	9	..	..	8	2	..	8	2	..	12	9	..	61	22
9	9	7	..	6	1	..	6	..	..	7	2	..	6	..	..	5	2	..	10	5	..	49	17
10	8	6	..	6	1	..	3	..	..	4	1	..	5	..	..	7	3	..	10	8	..	43	19
11	6	1	..	2	1	..	4	2	..	6	1	..	6	1	..	7	3	..	14	10	..	45	19
12	6	3	..	3	1	..	5	1	..	5	1	..	4	1	..	9	..	..	14	10	..	46	17
13	6	1	..	5	1	..	5	2	..	4	..	..	8	1	..	10	3	..	14	10	..	52	18
14	3	..	..	7	2	..	7	4	..	7	1	..	7	1	..	6	..	..	12	10	..	42	18
15	5	1	..	5	1	..	6	3	..	7	3	..	8	1	..	8	1	..	12	4	..	51	14
16	6	2	..	6	2	..	6	..	..	9	1	..	9	..	..	12	1	..	15	13	..	63	19
17	10	3	..	8	..	..	8	1	..	9	..	..	9	..	..	12	4	..	16	13	..	72	21
18	10	2	..	8	1	..	8	.	..	7	..	..	13	1	..	14	6	..	15	12	..	75	22
19	11	4	..	7	2	..	6	..	..	6	..	..	7	..	..	12	2	..	16	13	..	65	21
20	8	1	..	6	1	..	8	..	..	8	..	..	8	1	..	10	4	..	14	10	..	62	17
21	10	1	..	9	4	..	8	2	..	8	2	..	7	3	..	11	1	..	14	10	..	67	23
22	8	3	..	9	2	..	6	3	..	7	2	..	9	2	..	10	2	..	13	7	..	62	21
23	10	..	..	7	2	..	8	3	..	7	1	.	10	..	..	11	3	..	14	9	..	67	18
24	7	1	..	9	3	..	8	4	..	9	1	..	10	1	..	11	3	..	13	8	..	67	21
Total	200	73	..	170	40	..	166	34	..	171	19	..	202	25	..	241	66	..	322	225	..	1472	482

Grand Total: 1472 Pleasant, 482 Most Pleasant.

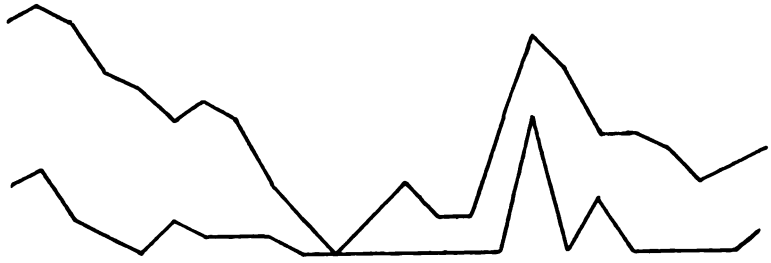
TABLE V.—COLOURS (TOTALITY OF ALL EXPERIMENTS, TABLE I. AND IV.)

Number of Colour	Black			Grey I.			Grey II.			Grey III.			Grey IV.			Grey V.			White			Total	
	Pleasant	Most Pleasant	Unpleasant	Pleasant	Most Pleasant	Unpleasant	Pleasant	Most Pleasant	Unpleasant	Pleasant	Most Pleasant	Unpleasant	Pleasant	Most Pleasant	Unpleasant	Pleasant	Most Pleasant	Unpleasant	Pleasant	Most Pleasant	Unpleasant	Pleasant	Most Pleasant
1	24	7	..	22	3	..	21	5	..	20	1	1	23	3	..	26	10	..	26	14	..	162	43
2	26	9	..	25	6	..	25	9	..	25	5	..	27	5	..	30	11	..	29	20	..	187	65
3	24	6	..	21	5	1	21	3	1	23	3	..	24	5	..	28	8	..	29	13	..	170	43
4	20	5	..	17	3	..	18	1	..	19	..	..	19	3	..	20	3	..	25	8	..	138	23
5	17	4	..	19	1	..	19	3	..	19	2	2	17	1	1	15	4	..	20	5	..	126	20
6	19	8	4	16	4	1	15	4	1	18	..	2	20	3	..	21	2	..	25	11	..	134	32
7	20	6	3	16	2	4	14	3	3	12	1	4	19	1	1	15	3	1	25	9	1	121	25
8	16	8	2	18	5	2	16	1	3	14	2	2	17	5	2	13	3	3	19	11	..	113	35
9	13	8	2	10	1	2	8	2	3	11	2	3	12	..	3	8	5	2	15	5	1	77	23
10	10	6	6	7	1	3	5	..	4	5	2	3	10	1	1	11	3	2	15	8	1	63	21
11	6	1	1	5	1	3	5	2	2	6	1	1	8	1	1	12	3	1	19	10	..	61	19
12	8	3	1	7	2	2	5	..	1	9	2	1	6	1	1	13	..	1	20	10	..	68	18
13	10	1	3	8	1	2	8	2	3	6	..	2	10	1	1	16	3	1	19	11	..	77	19
14	5	..	6	9	1	6	10	5	5	9	1	6	11	4	4	10	..	4	18	10	..	72	21
15	7	1	6	6	1	6	9	2	7	10	3	6	11	1	3	13	1	3	18	4	1	74	13
16	14	2	1	13	4	..	15	1	..	21	2	..	20	..	..	24	3	..	25	15	..	132	27
17	23	11	..	22	7	..	22	5	..	24	7	..	24	6	..	28	12	..	29	22	..	172	70
18	21	2	..	21	3	..	18	2	..	22	5	..	28	7	..	28	8	..	29	14	..	167	41
19	18	7	..	17	2	..	13	2	..	16	3	..	18	2	..	21	4	..	24	15	..	127	35
20	15	1	..	15	1	..	14	2	..	16	..	..	16	2	..	19	4	..	21	11	..	116	21
21	16	1	..	16	4	..	16	2	..	16	4	..	15	4	..	21	4	..	24	11	..	124	30
22	12	3	2	13	3	..	14	4	2	14	2	2	14	3	..	19	3	..	20	7	..	106	25
23	15	..	1	12	4	..	15	4	1	13	1	1	17	..	..	21	4	..	23	11	..	116	24
24	13	2	..	14	3	..	16	4	..	15	2	..	16	2	..	18	3	..	23	8	..	115	24
Total	372	102	38	349	68	32	342	68	36	363	51	35	402	61	18	450	104	18	540	263	4	2818	717

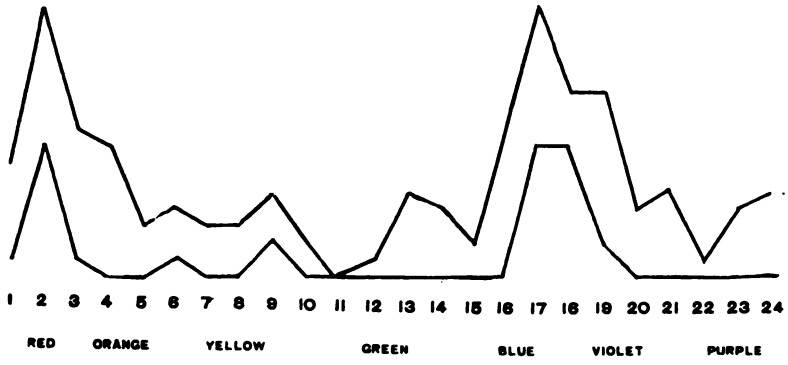
Grand Total: 2818 Pleasant, 717 Most Pleasant, 181 Unpleasant.



TINTS.

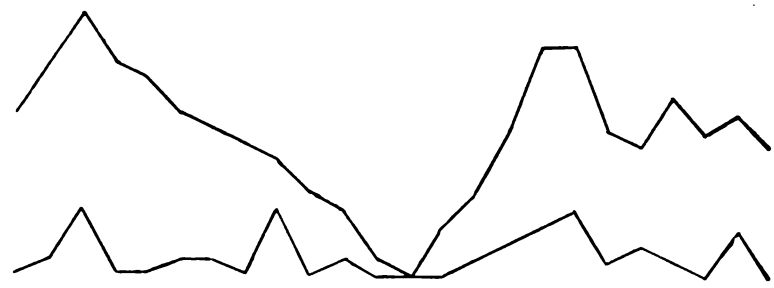


COLOURS.



SHADES.

PLATE I.—BLACK



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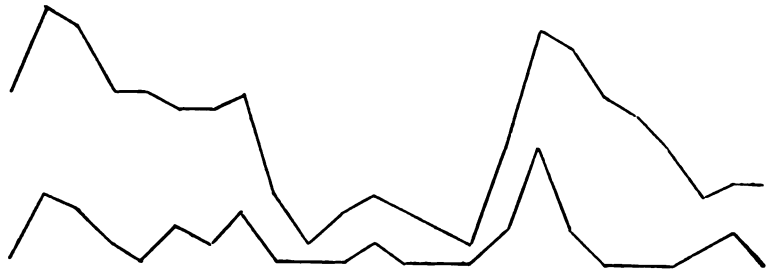
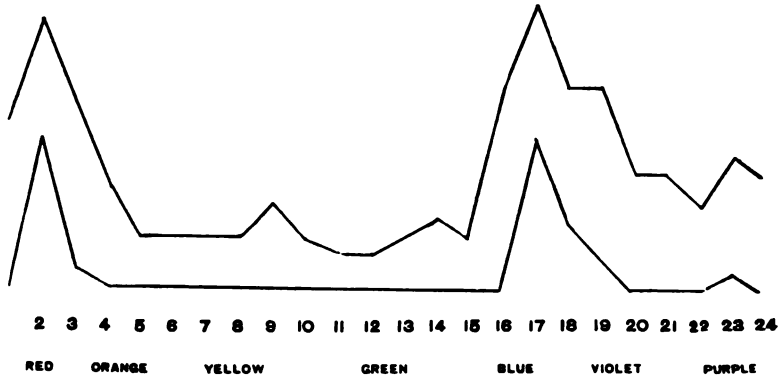


COLOURS.

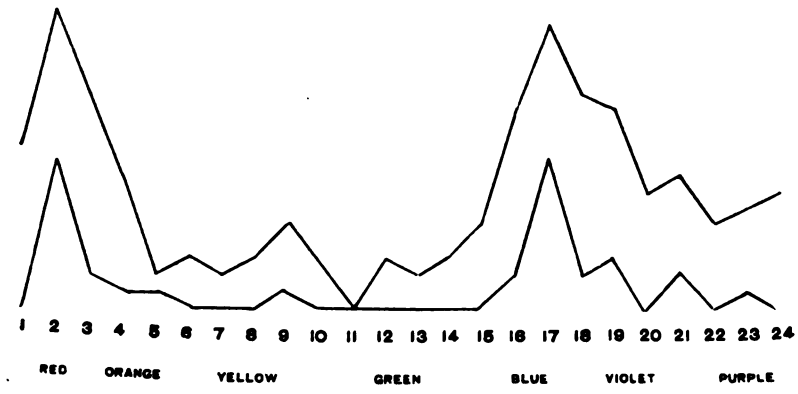


SHADES.

PLATE II.—GREY I

TINTS.

COLOURS.



SHADES.

PLATE III.—GREY II

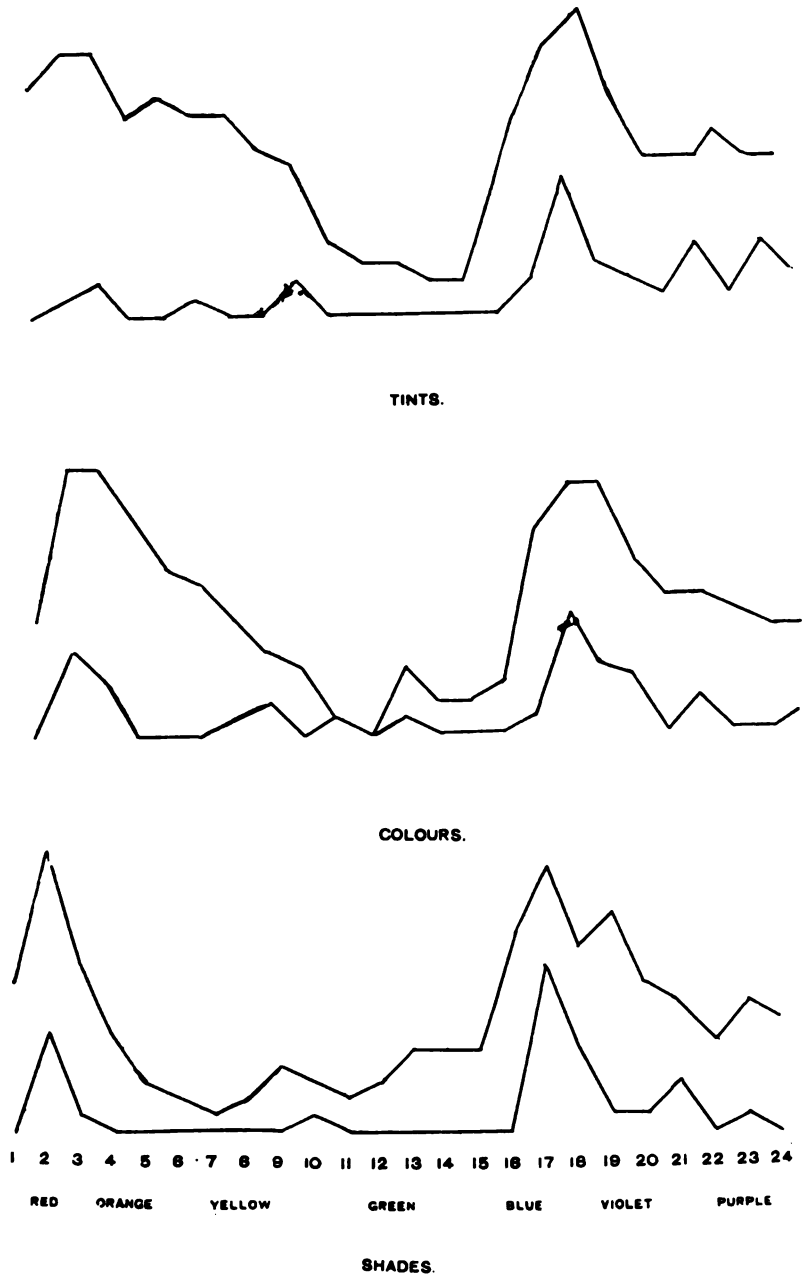


PLATE IV.—GREY III

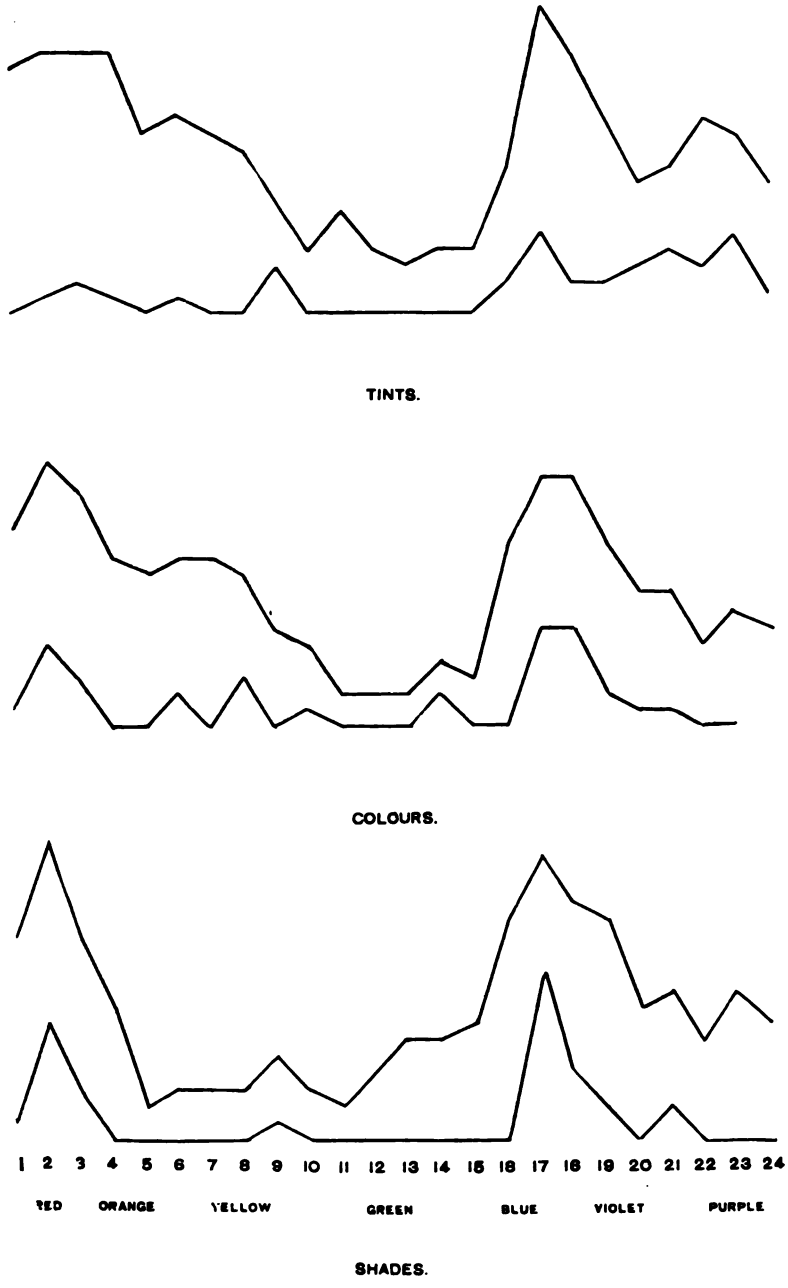
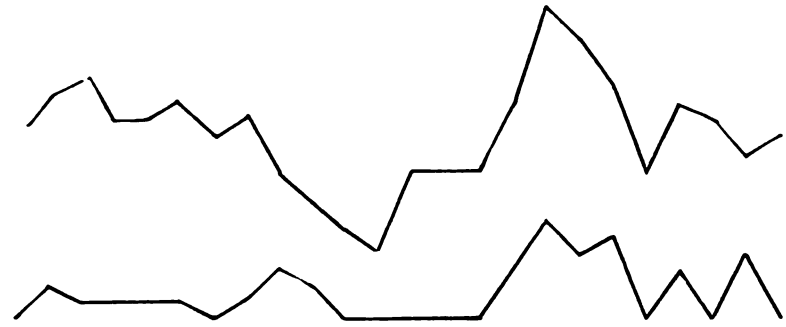
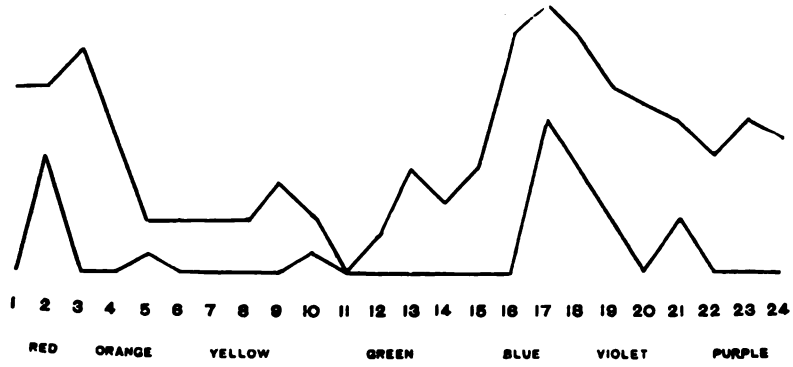


PLATE V.—GREY IV



TINTS.

COLOURS.



SHADES.

PLATE VI.—GREY V

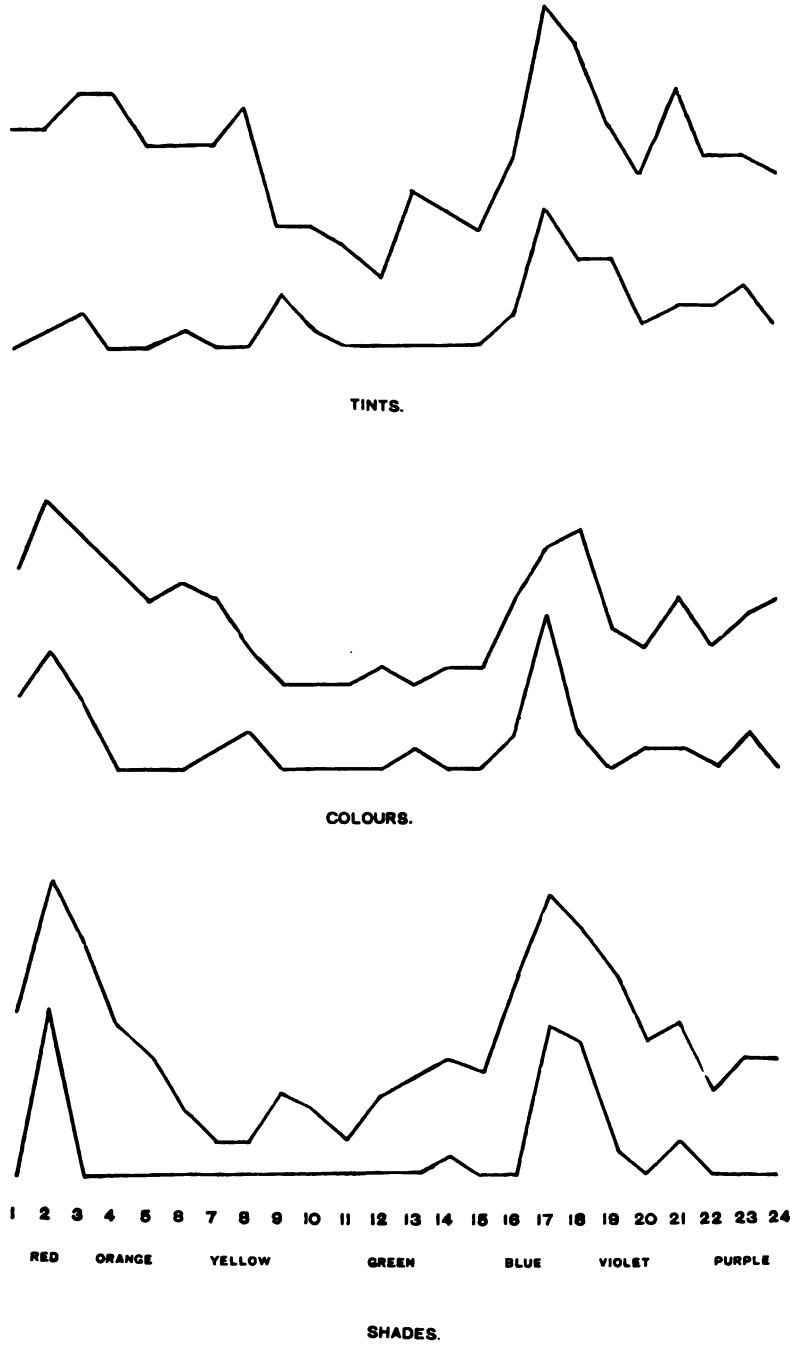


PLATE VII.—WHITE

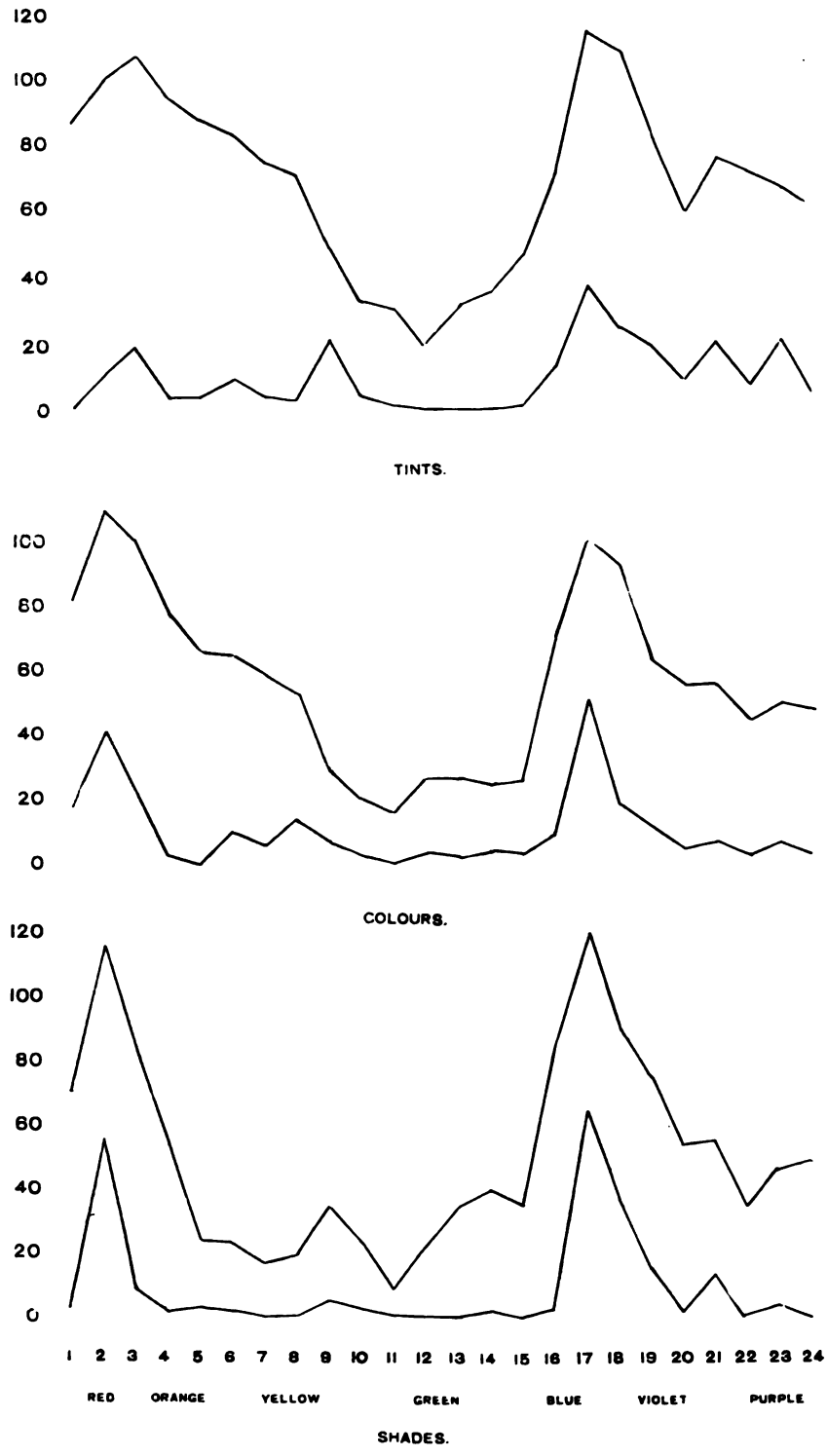


PLATE VIII.—COMBINATION CURVES

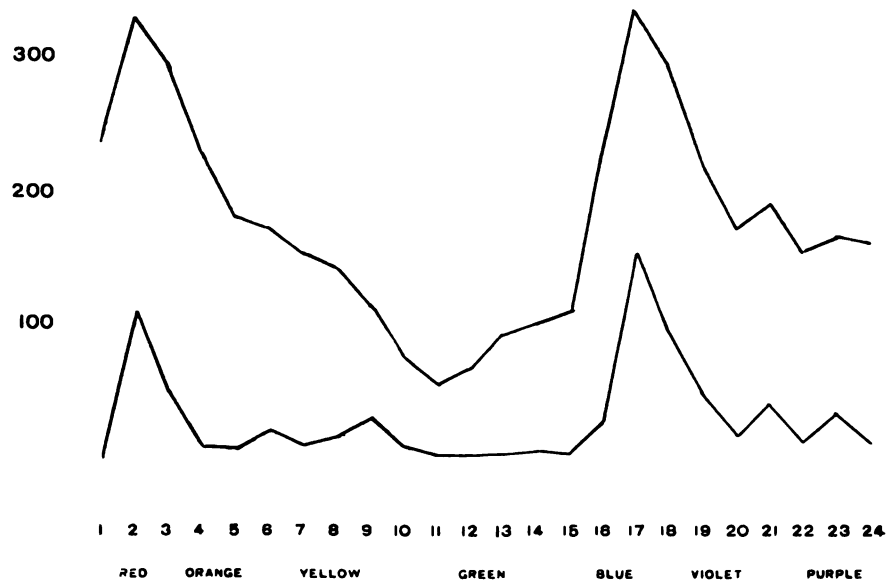


PLATE IX.—TOTAL COMBINATION CURVE

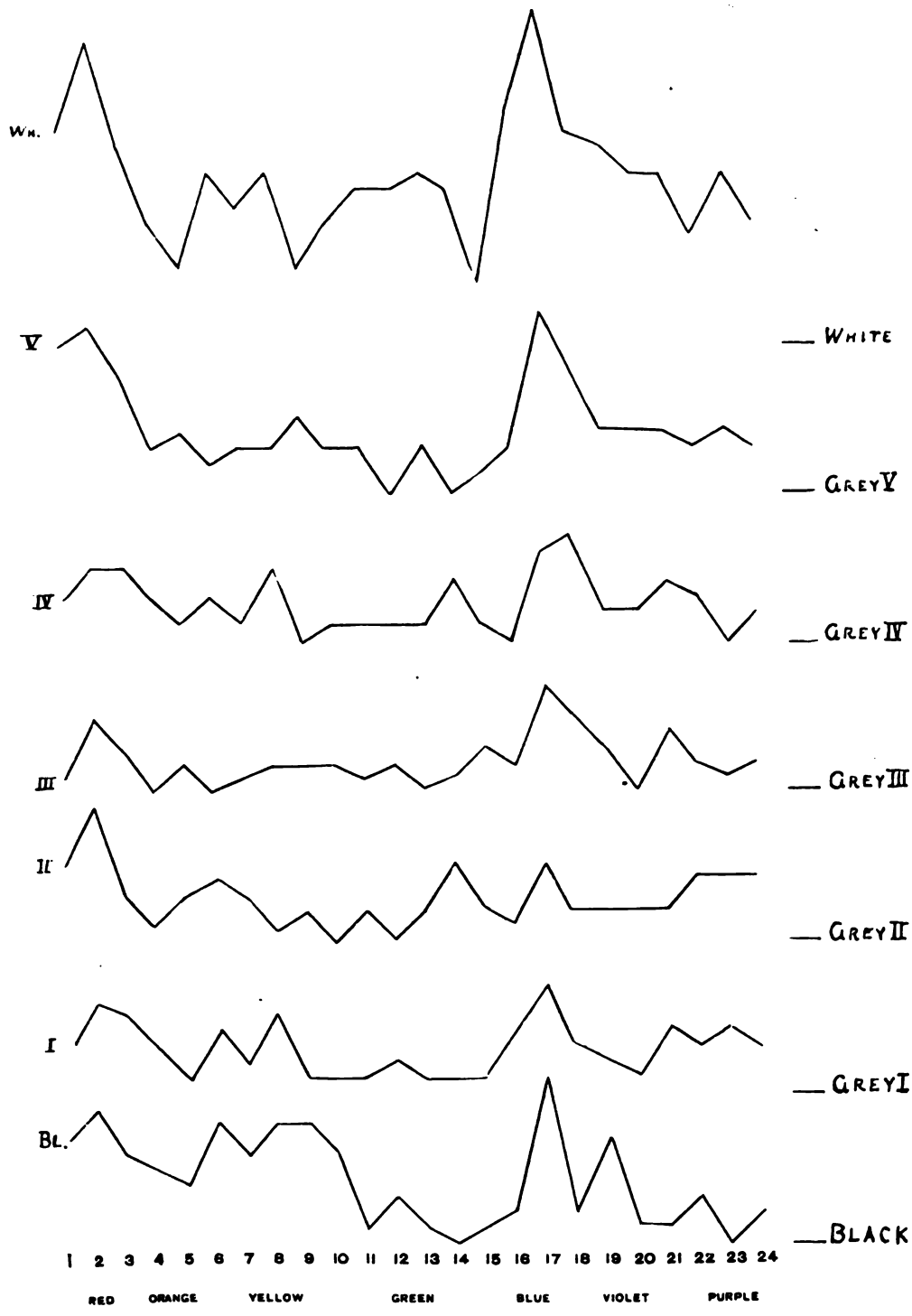


PLATE X.—MOST PLEASANT COMBINATIONS—COLOURS (TOTAL)

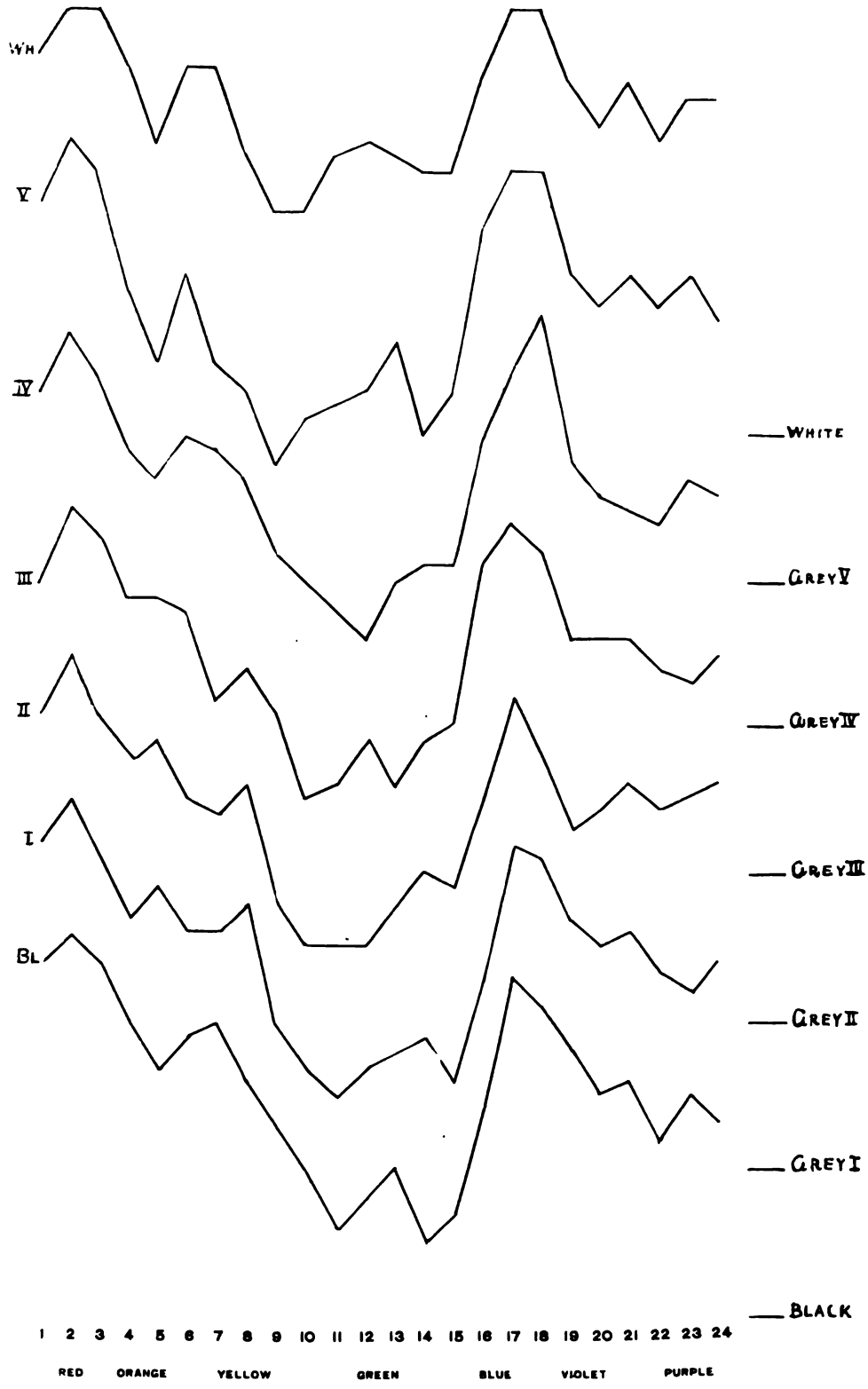


PLATE XI.—PLEASANT COMBINATIONS—COLOURS (TOTAL)

THE COMPLEMENTARY RELATIONS OF SOME SYSTEMS OF COLOURED PAPERS

BY

D. C. MacGREGOR, B.A. AND D. S. DIX, B.A.

THE COMPLEMENTARY RELATIONS OF SOME SYSTEMS OF COLOURED PAPERS

Complementary colours play a great rôle, not only in the physical consideration of the nature of light, but, to a much higher degree, in the psychological investigation of simultaneous contrast and after-images, and last but not least in colour æsthetics, where, for so long a time, it was the general belief that complementary colours afforded the most agreeable combinations. But the desire to attain perfect accuracy in the determination of the complementarism obviously does not keep pace with the increase of the importance of that phenomenon. For we notice that many physical, physiological, and psychological investigators seem to be satisfied with the conventional statements of pairs of complementaries, e.g., red and blue-green, orange and blue, etc.

Instead of adhering to such a gross and misleading verbal conventionality, it should be regarded as most desirable that in all investigations where coloured light, either reflected or transmitted, is used, the complementary relations of the qualities in question should be determined as accurately as possible. This has been done by Miss Baker[1] for the twenty-four qualities of Prang's standard colour papers, and also for the twelve spectrally pure colours used by her and produced by Kirschmann's apparatus. We have tried to do the same for the Milton-Bradley educational colour papers, and for the thirteen papers of Professor Hering procured from the mechanician of Hering's Institute, Mr. Rothe.

Our apparatus, different from that used by Miss Baker, which consisted of ordinary rotating discs requiring to be stopped for each change of the sectors, was arranged as follows. Two Marbe's apparatus were placed side by side and driven by one motor which gave the discs a speed of from forty to fifty revolutions per second. One of the Marbe's apparatus (A) carried the coloured discs, and the other (B) a black and white disc, the relation of which could be varied so as to produce any grey desired. When we had succeeded

[1] *Experiments on the Æsthetic of Light and Colour.* (University of Toronto Studies, Psychological Series, vol I, pp. 201 etc., and vol. II, No. 1, pp. 27 etc.)

in A in obtaining colourless light, we produced a grey of exactly the same light intensity in B, and thus found an equation. As we did not find any two colour qualities in the above-mentioned systems to be exactly complementary, it became necessary in each experiment to introduce a third quality to secure colourless light. The Marbe's apparatus only allows for the continuous variation of the angular relation of two discs, consequently the third quality had to be varied in the old-fashioned way, i.e., by discrete steps of degrees.

The experiments were made in a room with indifferently grey walls, and the discs were illuminated by light from a window parallel to the plane of the discs and straight before it at a distance of six feet. The window received its light chiefly from the sky and from the grey walls of the opposite wing of the university building. We noticed, however, in the afternoon, when these walls were in the direct sunshine, that they seemed to have a yellowish tinge, consequently we made all our experiments (with a single exception) in the forenoon, when the walls were in the shade and the illumination was chiefly from the sky. The observer was placed directly before the discs at a distance of five feet, and was required to maintain accurately the same position; for we noticed that, on account of the slight glaze which coloured papers usually have, be it ever so little, the reflection in a slanting direction is different from that in the normal. This is noticeable with regard not only to the quality of the light, but also to its intensity. An equation, valid for an eye directly facing the discs at the front, usually has to be changed for several degrees in order to be satisfactory for an eye observing in a slanting direction, say thirty degrees.

The equations, obtained in this way and reported in the following tables, are in each case the average of two decisions of two observers. The Milton-Bradley system of coloured papers distinguishes eighteen colour qualities, named as follows: violet-red, red, orange-red, red-orange, orange, yellow-orange, orange-yellow, yellow, green-yellow, yellow-green, green, blue-green, green-blue, blue, violet-blue, blue-violet,

violet, and red-violet. The designation in the table is by the initials of these names. Bl. and W. stand for Black and White.

268½	Bl. +	91½	W. = 228½	V.R.	+ 26	B.G.	+ 105½	G.
278½	Bl. +	81½	W. = 202	R.	+ 136½	B.G.	+ 21½	G.B.
254	Bl. +	106	W. = 135½	O.R.	+ 191	B.G.	+ 33½	G.B.
253	Bl. +	107	W. = 113½	R.O.	+ 199	B.G.	+ 47½	G.B.
240	Bl. +	120	W. = 99	O.	+ 176	B.G.	+ 85	G.B.
237½	Bl. +	122½	W. = 105	Y.O.	+ 122	B.G.	+ 133	G.B.
221½	Bl. +	138½	W. = 120½	O.Y.	+ 5	B.G.	+ 234½	G.B.
207	Bl. +	153	W. = 138½	Y.	+ 110	G.B.	+ 111½	B.
223½	Bl. +	136½	W. = 147	G.Y.	+ 123	V.	+ 90	B.V.
221	Bl. +	139	W. = 126	Y.G.	+ 186	R.V.	+ 48	V.R.
268	Bl. +	92	W. = 131	G.	+ 48	R.V.	+ 181	V.R.
275½	Bl. +	84½	W. = 142	B.G.	+ 40½	V.R.	+ 177½	R.
206½	Bl. +	153½	W. = 240	G.B.	+ 116	O.Y.	+ 4	Y.
213½	Bl. +	146½	W. = 184½	B.	+ 69	Y.	+ 106½	G.Y.
214½	Bl. +	145½	W. = 197½	V.B.	+ 43	Y.	+ 119½	G.Y.
183	Bl. +	177	W. = 194	B.V.	+ 16	Y.	+ 150	G.Y.
234½	Bl. +	125½	W. = 235	V.	+ 78½	G.Y.	+ 46½	Y.G.
218	Bl. +	142	W. = 225½	R.V.	+ 27	G.Y.	+ 107½	Y.G.

These results may be diagramatically shown as in Plate A.

The Hering system of coloured papers comprises thirteen colour qualities, to which we have applied the following names, merely for use in this paper: red (1), red (2), orange-red (3), orange (4), orange-yellow (5), yellow (6), yellow-green (7), green (8), blue-green (9), green-blue (10), blue (11), violet (12), and violet-red (13). We obtained the following equations:

288	Bl. +	72	W. = 141½	R.(1)	+ 101½	G.B.(10)	+ 117	B.G.(9)	
277	Bl. +	83	W. = 121	R.(2)	+ 117	G.B.(10)	+ 122	B.G.(9)	
285½	Bl. +	74½	W. = 118½	O.R.(3)	+ 134	G.B.(10)	+ 107½	B.G.(9)	
271½	Bl. +	88½	W. = 87	O.(4)	+ 188½	G.B.(10)	+ 84½	B.G.(9)	
266½	Bl. +	93½	W. = 99	O.Y.(5)	+ 33½	B.(11)	+ 227½	G.B.(10)	
249½	Bl. +	110½	W. = 119	Y.(6)	+ 177½	B.(11)	+ 63½	G.B.(10)	
279½	Bl. +	80½	W. = 154	Y.G.(7)	+ 87½	V.R.(13)	+ 118½	V.(12)	
292½	Bl. +	67½	W. = 161	G.(8)	+ 149½	V.R.(13)	+ 49½	V.(12)	

$282\frac{1}{2}$Bl. + $77\frac{1}{2}$W. = 185 B.G.(9) + $102\frac{1}{2}$V.R.(13) + $72\frac{1}{2}$R.(1)
$270\frac{1}{2}$Bl. + $89\frac{1}{2}$W. = $262\frac{1}{2}$G.B.(10) + 56 O.Y.(5) + $41\frac{1}{2}$O.(4)
259 Bl. + 101 W. = 210 B.(11) + 107 Y. (6) + 43 Y.G.(7
$265\frac{1}{2}$Bl. + $94\frac{1}{2}$W. = 216 V.(12) + $51\frac{1}{2}$Y. (6) + $92\frac{1}{2}$Y.G.(7
290 Bl. + 70 W. = $183\frac{1}{2}$V.R.(13) + 92 B.G.(9) + $84\frac{1}{2}$G.(8)
These equations are represented in Plate B.

Our diagrams are of very similar construction to those in Miss Baker's first article.[1] It is quite characteristic that there is a curious coincidence in the general configuration of our diagrams representing the Milton-Bradley and Hering systems and Miss Baker's which stands for Prang's system. It will be found that in all of them, the lines do not pass through the centre as they should, but the points of intersection form a certain triangular figure which is very similar in all the three diagrams. The cause of this phenomenon may be found in the following circumstances. The eccentric position of the triangle is due to the preponderance of the red. orange and yellow qualities at the expense of the others. That the points of intersection cluster around the points of the triangle is probably due to the fact that the pigments employed in dveing these papers are not so numerous as the papers themselves of the system. Whilst there are apparently six different qualities from the red to the yellow and just as many from the blue to the red, there are probably only a few pigments used, and the intermediate qualities are made up by mixtures. The change in quality is then greatest at the transition from yellow to green, from green to blue, and from violet to red.

Plate B of Miss Baker's second article[2] shows essentially different features. The territory of intersection is still eccentrical on account of the selection of qualities, but it is reduced to a very small area; and of the triangular structure of it, only traces are left. This is easily explained when we consider that the colours used here were approximately spectrally pure. If they had been absolutely pure, there would have been no trace at all remaining of that triangular structure.

[1] Univ. of Toronto Studies, Psych. Ser., I, 201 etc.
[2] Univ. of Toronto Studies, Psych. Ser., vol. II., No. 1, p. 38.

The results of Miss Baker's and those of our determination of the complementary relations show decidedly that the three systems of pigment papers most in use for scientific purposes are rather poor representatives of the true manifoldness of colour qualities. and the conclusions which we have arrived at may in this respect serve as a suggestion for improvement.

The writers desire to acknowledge their indebtedness to Professor Kirschmann, at whose suggestion and under whose direction the above reported experiments were carried out.

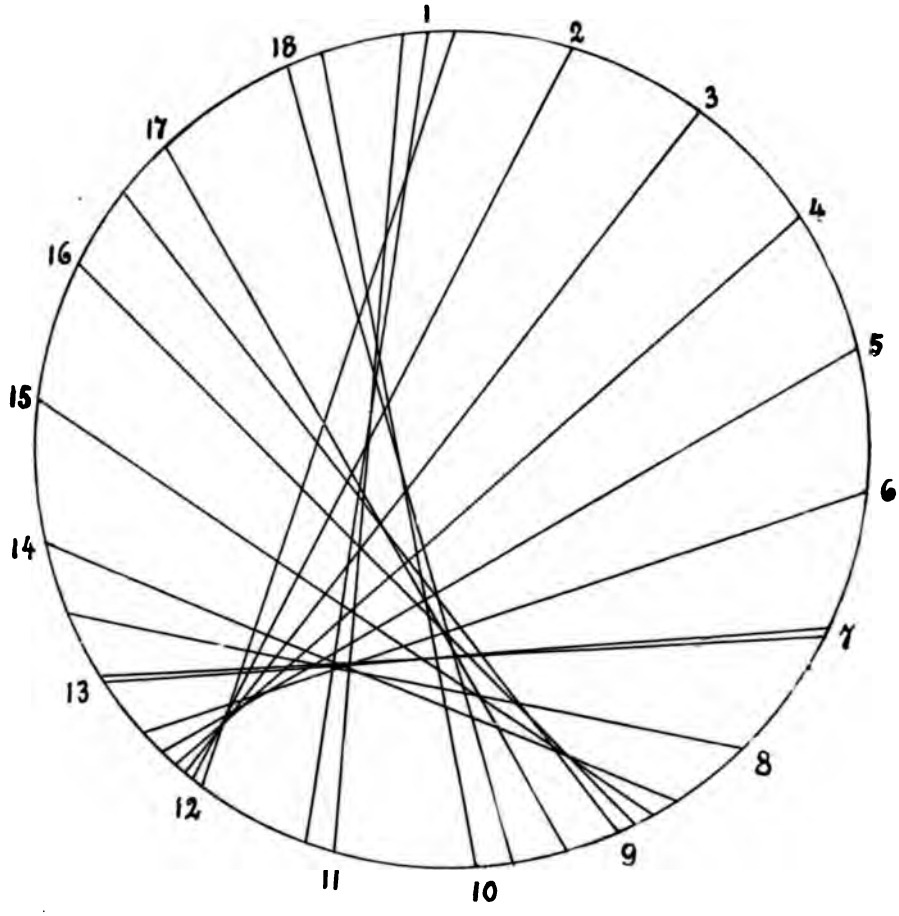


PLATE A.—MILTON-BRADLEY'S COLOURS

1. Violet red.
2. Red.
3. Orange red.
4. Red orange.
5. Orange.
6. Yellow orange.
7. Orange yellow.
8. Yellow.
9. Green yellow.
10. Yellow green.
11. Green.
12. Blue green.
13. Green blue.
14. Blue.
15. Violet blue.
16. Blue violet.
17. Violet.
18. Red violet.

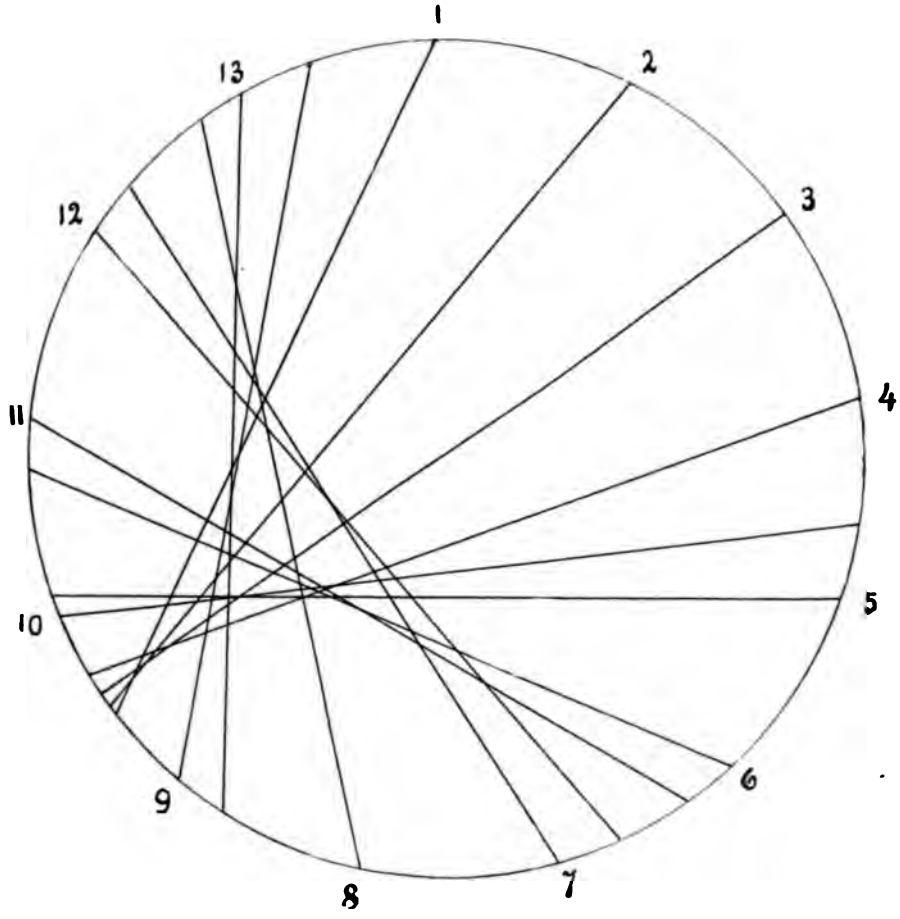


PLATE B.—HERING'S COLOURS

1. Red (1).
2. Red (2).
3. Orange red.
4. Orange.
5. Orange yellow.
6. Yellow.
7. Yellow green.
8. Green.
9. Blue green.
10. Green blue.
11. Blue.
12. Violet.
13. Violet red.

SOME PHOTOMETRICAL MEASUREMENTS

BY

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SOME PHOTOMETRICAL MEASUREMENTS

In Volume V (pages 292 et seq.) of the *Philosophische Studien* Dr. Kirschmann describes a simple apparatus for the measurement of the light intensities of black, grey, and white papers in terms of one another. This apparatus has been improved and used in the Psychological Laboratory of the University of Toronto for measuring the intensities of the Prang and Milton-Bradley papers and other uncoloured pigments. While the main part of the apparatus, the disc with its movable sectors and the dark space, remained essentially the same, appropriate arrangements for securing constancy of illumination were added and the following is the description of the apparatus as now used. A large disc, made of stiff cardboard or aluminium and covered with Milton-Bradley's best white paper, is divided into quadrants, and from two opposite quadrants, about one inch from the outer edge, sections are cut out one inch in width, and 90° in length, and a graduated scale is made on the remaining quadrants. A smaller disc of the paper, of which the intensity is to be compared with that of the white is made so that the edge of this smaller disc reaches just beyond the inner edge of the open section. From a third disc two opposite sections of 120° each are removed so that the outer edges of this sector reach the inner side of the graduated scale, while the inner edges of the sector leave exposed two sections of the grey paper to be measured. each section 120° by one inch in width. A fourth disc with two opposite sections of 90° each removed forms a similar sector but with diameter equal to that of the first disc, and may be used as a "vernier" for the observations made with the preceding or smaller sector. When these are placed on a motor in the order named, and then revolved with sufficient speed to secure the complete validity of Talbot's Law,[1] it is evident they will make two grey rings of different intensities surrounded by a white ground, but the outer ring will be influenced by what is behind the open section of the large disc. To get the lowest possible intensity in combination with the outer ring a box in

[1] See Articles of Professor Marbe on Talbot's Law.

the form of a truncated pyramid is lined with black velvet, the angular relation of the sides of the box to each other being such that no reflection is given through the small opening when the box is placed immediately behind the open section of the large disc. To avoid the effect of a changing illumination as in daylight, the experiments are made in a dark room with light only from four (or two) Auer lamps placed immediately over the revolving discs, and the illumination from the lamps, whose flames are in the focal line of a parabolically curved mirror, is reflected upon the disc by another and plane mirror in front, attached to a wooden screen behind which the observer sits and compares the intensities of the two grey rings on the white ground. It is quite evident that the intensities of the two papers can be compared at different positions of the sectors; thus a number of observations can be made with different combinations of the papers to be measured, as when the larger sector is placed at 10°, 15°, 20°, 25°, etc. When the larger sector is placed, say, at 40° and the angular widths of the opening and the grey to be measured are equal, it is evident that the outer ring will be considerably darker than the inner ring because the absolute black of the opening is, of course, much darker than the grey paper. By moving the smaller sector to the left, grey is added to the inner ring, i.e., more of the grey paper is exposed until a point is reached where the intensities of the two rings are estimated as equal. As a criterion for this condition we may use the complete blending into one ring without any separating line. From the point where the intensities are judged to be equal more grey may be added, without any noticeable difference until the point is reached where noticeable change begins. The average of the two judgments may be taken as the best procurable with the use simply of the smaller sector. But the changes produced by the smaller sector are comparatively large. For if the outer ring be 40° and the inner one 42°, and one degree be added to the latter, the relation of the two rings is changed from $\frac{40}{42}$ to $\frac{40}{43}$, that is, a difference of $\frac{1}{43.43}$ or 2.215%. Now the use of the larger sector makes possible a finer variation. If

in the above case the larger sector be moved for one degree the same angular amount is added (or taken away) from both rings. Consequently the change is from 40 and 42 to 41 and 43, i.e., the relation is changed from $\frac{40}{42}$ to $\frac{41}{43}$, that is, a difference of $\frac{1}{903}$ or 0.111%. Thus the larger sector, though without a graduated scale, serves as a kind of "vernier." The larger sector is used in the following manner. The limit of the adjustment for the smaller sector is half a degree. Thus, after ascertaining that position of the smaller sector where the two rings best blended, there would be found the limits for the position of the larger sector for which this blending was not destroyed. The average of the numbers indicating the limits would be taken into account in calculating the results.[1]

Let the angular opening of the disc into the velvet-lined box be a°. Then the components of the outer ring of grey are (360—a)° of white and a° of absolute black. Let the intensity of the absolute black be 0, and that of one degree of white be represented by x. The intensitv of the outer ring, then, is $(360-a)x + a \times 0$.

Let the number of degrees of grey paper be represented by b, and let the intensity of one degree of the grey compared with white be 1. Then the components of the inner ring are (360—b)° of white and b° of grey. The intensity of the inner ring is $(360-b)\ x + b \times 1$.

When the two rings are judged as equal there is the following equation:—[2]

$$(360-a)x + a \times 0 = (360-b)x + b \times 1$$
$$360x - ax = 360x - bx + b$$
$$bx - ax = b$$
$$x = \frac{b}{b-a}$$

Since 1900, Professor Kirschmann has given the writer charge of the photometrical measurements required for various purposes and the following tables contain a few results which

[1] The accompanying cut (Plate C) from a stereoscopic photograph may be of some assistance in understanding the apparatus.

[2] *Philos. Studien*, V, 297.

might be of interest generally and in connection with other articles in this number. Table I contains results of experiments made in ordinary daylight by three observers, Messrs Coleman, Farrell and Smith. The number in the column headed "relation to white" indicates how many times as bright Milton-Bradley's white was as the grey or black paper named in the first column. In the second column, headed "Average," all the numbers refer to black as one. They indicate how many times as bright was the grey or white in question as the Milton-Bradley black which is taken as unity.

Table II contains the results of experiments made in 1901-2 by Messrs Van Wyck and Archer, and in 1902-3 by Messrs Ross and Graham.

In all these results of Table II artificial light (Auer light) was used, in those of Table I ordinary daylight. After the explanation given for Table I, Table II is easily understood. The results of Table II are different from those of Table I because of the different conditions of illumination. Also the lead pencil and China ink were not the same for the different groups.

Finally, it may be mentioned that the coincidence of the average to the second decimal of the four series of Van Wyck and the four of Archer is purely accidental, but a still greater freak of accident is the curious fact that when Messrs. Ross and Graham made the experiments with the same paper the averages of the results of six series of each again coincided to the third decimal.

TABLE I.—ILLUMINATION BY DAYLIGHT.

Name of Paper or Pigment	Smith		Coleman		Farrell		Total (Average)		Total (Average)
	Num. of Trials	Ratio to White	Num. of Trials	Ratio to White	Num. of Trials	Ratio to White	Num. of Trials	Ratio to White	Referring to M. Bradley's Black as 1
Milton Bradley's Black	3	44.542	6	42.997	2	40.83	11	43.074	1
" " Neutral Grey I	2	2.638	2	2.616	3	2.567	7	2.601	16.561
" " Neutral Grey II	4	3.625	3	3.688	4	4.025	11	3.782	11.389
" " Warm Grey I	..	....	3	2.675	.	....	3	2.675	16.148
" " Warm Grey II	..	....	5	5.130	5	5.410	10	5.270	8.156
" " Cool Grey I	..	...	4	2.212	3	2.061	7	2.147	20.062
" " Cool Grey II	..	....	5	3.655	4	3.798	9	3.718	11.585
" " White	..	....	.	....	.	....	.	....	43.074
Prang's Lighter Grey	..	....	3	2.499	4	2.507	7	2.504	17.202
" Light Grey	..	....	3	4.515	4	4.216	7	4.344	9.916
" Grey	..	....	3	6.564	4	6.597	7	6.583	6.467
" Dark Grey	..	....	7	8.773	4	8.661	11	8.732	4.933
" Darker Grey	..	....	6	10.208	4	9.959	10	10.109	4.261
Black Card-Board	..	....	4	25.682	.	....	4	25.682	1.697
Lead Pencil (Faber BB)	2	13.475	3	11.435	6	13.688	11	13.031	3.305
China Ink	5	15.458	3	16.097	4	17.058	12	16.151	1.697

TABLE II.—ILLUMINATION BY AUER-LIGHT.

Name of Paper or Pigment	Archer		Van Wyck		Graham		Ross		Total (Average)		Total (Average)
	No. of Trials	Ratio to White	No. of Trials	Ratio to White	No. of Trials	Ratio to White	No. of Trials	Ratio to White	No. of Trials	Ratio to White	Referring to M. Bradley's Black as 1
Milton Bradley's Black	..	..	8	40.620	..	..	..	..	8	40.620	1
" " Neutral Grey I	3	2.930	4	3.015	6	3.365	6	3.321	19	3.209	12.658
" " Neutral Grey II	6	5.138	5	5.503	6	4.107	6	4.392	23	4.754	8.544
" " Warm Grey I	4	3.175	4	3.710	6	3.644	6	3.586	20	3.546	11.455
" " Warm Grey II	4	7.110	4	7.110	6	5.147	6	5.147	20	5.933	6.846
" " Cool Grey I	4	2.622	4	2.600	6	3.286	6	3.505	20	3.082	13.180
" " Cool Grey II	4	7.610	4	7.750	6	4.654	6	4.863	20	5.925	6.856
" " White	..	..	..	..	..	..	..	..	..	..	40.620
Prang's Lighter Grey	3	2.444	4	2.990	6	3.754	6	3.837	19	3.413	11.902
" Light Grey	4	5.086	4	5.091	6	4.778	6	5.117	20	5.004	8.116
" Grey	4	8.873	8	9.286	6	8.303	6	7.951	24	8.591	4.728
" Dark Grey	..	..	..	..	6	11.483	6	11.682	12	11.583	3.507
" Darker Grey	..	..	10	15.618	6	15.330	6	14.483	22	15.230	2.667
Black Card-Board	3	31.68	4	33.450	..	..	..	..	7	32.690	1.243
Lead Pencil (Faber BB.)	3	14.82	4	10.960	..	..	..	..	7	12.614	3.220
China Ink	..	..	3	22.560	..	..	..	..	3	22.560	1.801
Printers' Ink	..	..	..	..	4	22.644	4	21.584	8	22.114	1.837
Printers' Ink (Thicker)	..	..	..	..	4	24.434	4	24.392	8	24.413	1.664

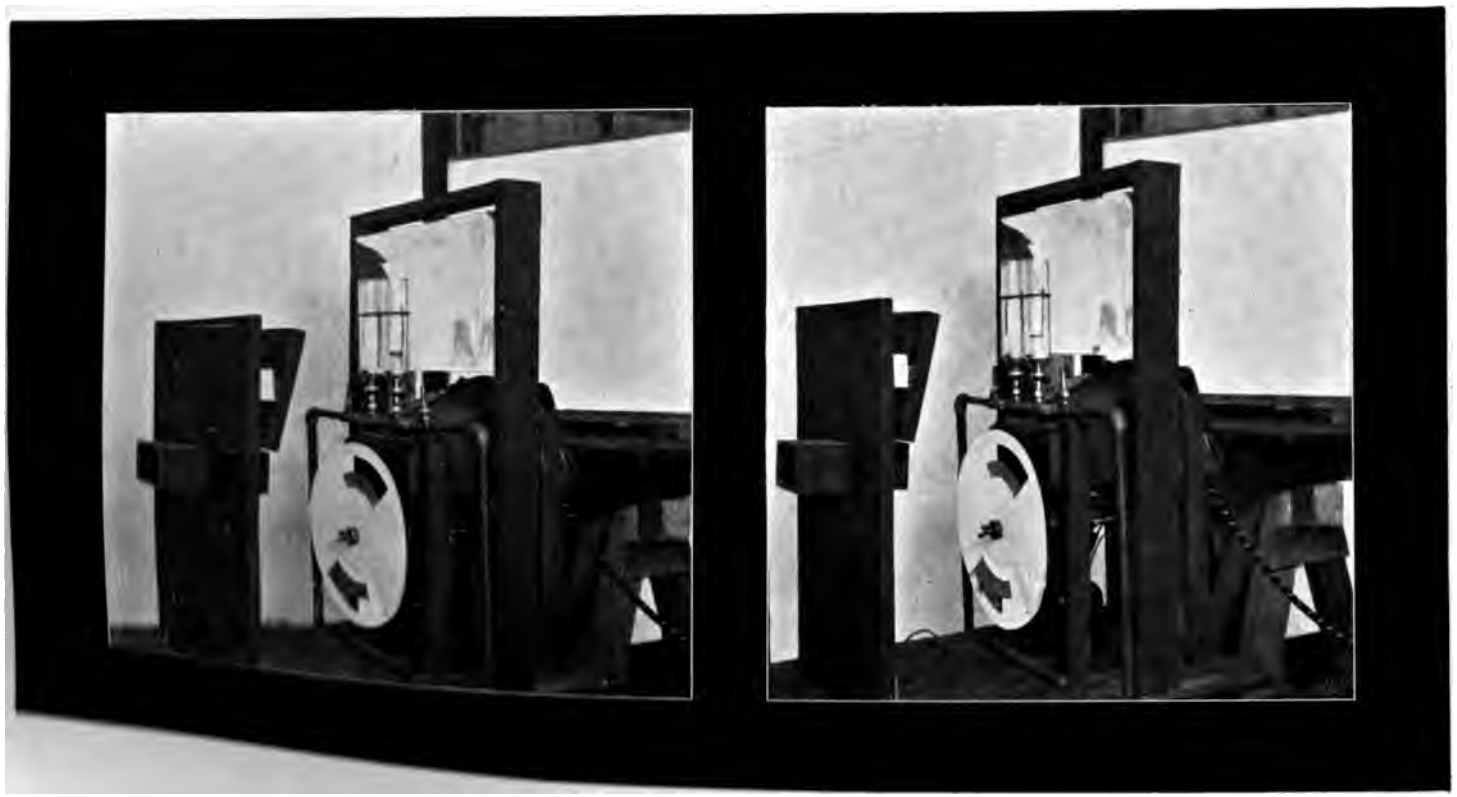


PLATE C.

STEREOSCOPIC VISION

AND ITS RELATION TO INTENSITY AND QUALITY OF LIGHT SENSATION

FIRST ARTICLE

STEREOSCOPIC VISION AND INTENSITY

BY

T. R. ROBINSON, B.A.

STEREOSCOPIC VISION IN ITS RELATION TO INTENSITY OF LIGHT SENSATION

I. INTRODUCTION—STATEMENT OF THE PROBLEM

Experimental psychology no longer needs, as at an earlier day, to defend its claim to a place among the sciences. The fact is now generally and cordially recognized that even those phenomena of experience which are within the domain of physical science cannot be fully understood until they have been regarded, not only from the abstract point of view of the physical sciences, but also from the direct standpoint of psychology, i.e., the standpoint of immediate experience. The best proof of this fact, if proof were still needed, would be furnished by such subjects as that of which the following pages treat, subjects, namely, which lie on the borderland of the physical, the physiological and the mental, and are of about equal interest to each of these sciences. We are landed in glaring inconsistencies and contradictions of actual experience if we attempt to treat such a subject as visual perception of depth or distance from a purely physiological standpoint. An excellent illustration of this is afforded by a recent article of Storch.[1] In an earlier article, Dr. Storch had discussed the point that the perception of an object does not consist simply in a complex of sensations, but that in addition there is a spacial element which is essential to the perception of an object. This spacial element in all our perceptions, he now goes on to say, must rest on the same material process in the cortex : so that we have a nervous organ, the excitation of which comes into our consciousness as space. He calls this organ the stereo-psychic field, and its anatomical elements stereons. Each stereon sends its dendrites into our several sensoria, and stretches its neurites into the motorical zones. In the stereons three different chemical actions are going on, each of which is, as to its intensity, independent of the others. These processes we do not notice directly. We notice only the acceleration and retardation of them. To these three "chem-

[1] *Der Wille und die räumliche Moment in Wahrnehmung und Vorstellung.* (Pflüger's Archiv, XCV, 305 etc.)

isms," or chemical processes, corresponds the arrangement of the perceived points in the directions right and left, up and down, near and far. The orientation is not given alone by the sense of sight, but can be furnished just as well by the ear labyrinths and by all other sense-organs. "Whether the changes in the stereo-psychical field happen from inner or outer causes, they must always appear in our consciousness as one of the possible combinations of three elements, as line, surface or solid, as direction-complexes of one, two or three-dimensional nature."

Without entering into a discussion of this alleged "space-organ" it will suffice to point out some of the assumptions which Storch finds it necessary to make in the application of his theory to experience. In the first place, he distinguishes between what he calls the "visual form" and the "real form" of perceived objects. "Neither in monocular nor in binocular vision is the spacial arrangement and form of the things which we really perceive simply the subjective aspect which is given by the stimulus. Entirely without our will the visual form is suppressed by the real form of the object.....The spacial element of visual perception has two components, one, independent of all experience, is caused by the stimulus. This is the visual form, which comes into our consciousness as certain complexes of a two or three-dimensional nature." This visual form or space component furnished by the senses Storch calls the immediate element of visual perception. The other component, which partially or completely suppresses the former, is the real form of the thing, which Storch calls the mediate spacial element, or associative component of visual perception. This distinction of real form from visual form involves a strange confusion of thought, and is wholly inconsistent with Storch's theory. If the "form" given in the stimulus is not seen, but is suppressed or altered by something else called the "real form," why call the former "visual"? Again, on Storch's theory, since complexes of sensation have not spacial quality without the excitation of a special "space-organ," it must be through the excitation of that organ that we get the

form that we perceive ; else whence comes the "real" form ? For if the latter is furnished neither in the sensation complex nor by the stimulation of the "space-organ," whence, on this physiological basis, do we get it ?

Another curious expression employed in the development of this physiological theory, and one to which its author attaches much significance, is the "absolute size" of objects. It is clear, he says, that if we had nothing but visual perceptions we should never attain to the presentation of real object forms. There is another necessary property of objects seen, which cannot be explained by the perception simply ; it is the absolute size. "Halte ich meine Hand etwa 25 cm. von meinem Gesicht entfernt, so erscheint sie nun keineswegs doppelt so gross als in 50 cm. Entfernung. Ich sehe sie in beiden Fallen in ihrer wirklichen Grosse. Den Grössen der Netzhaut-bilder gemäss durfte das nicht der Fall sein." But on this point the author of the theory has simply allowed it to mislead him as to the facts. The experiment has but to be tried to show at once that the case is just exactly as he says it is not. The hands are somewhat too large to be conveniently compared at the distances at which they can be held. But if the experiment be made with two coins, say a ten-cent piece and a half-dollar, the former held about a foot from the eye, the latter about two feet, they appear equal in diameter. To perceive them so it is only necessary to pay attention to what is seen, and to avoid being influenced by what is known regarding the physical measurements of the objects. The same remark applies to the other case cited, that of a grown person on the opposite side of the street appearing larger than a child near to the observer, although the retinal image of the latter is greater. This would never occur if the grown person were dressed like a child, and had not about him any of the signs which in our past experience have been associated with larger size. What happens in this case is that we pay attention to the memory-image associated with a certain dress, etc., rather than to what we actually see. Dr. Storch, indeed, comes very near to acknowledging this in his remark about the necessity of learn-

ing perspective drawing, which he illustrates by the known fact that children drawing a face sometimes draw the nose as in profile and then add the two eyes and the mouth.[1]

These examples of the facilith with which the attempt to account for facts of visual perception upon a purely physiological basis leads to assumptions which are quickly disproved by reference to the facts themselves show the necessity for supplementing the physical and physiological investigations by psychological experiment, i.e., by careful examination, under controllable conditions, of the facts as they are directly known to us. Storch's work having been referred to as an illustrative case, mention may be made of another assumption, which is common to him and to others who have dealt with this subject, viz., that in monocular vision we have only lines and surfaces, but no depth. This is very far from being in accordance with the facts. In monocular vision there are factors of depth perception the development of which in the case of persons who have suffered the loss of one eye may result in an estimation of distances no less accurate than that of people with two eyes. Indeed to speak of perceiving a surface without having the third dimension at all is obviously self-contradictory. If a person sees a surface, that surface must lie at some distance from him. For he would not even see a surface unless he himself were outside the surface. But in being outside the surface which he sees, he already has the third dimension.[2] The perception of depth is not entirely

[1] See, for a discussion of this latter subject from a more thorough standpoint, Kirschmann's *Die psychologisch-ästhetische Bedeutung des Licht- und Farbencontrastes* (Philos. Stud. VII, p. 362), and the book published under the pseudonym of C. E. Rasius, *Rechte und Pflichten der Kritik*, p. 91. Kirschmann points out that we need to learn perspective drawing only in order to undo the influence of prejudice or prepossession. He claims that a correct observer, who is able to separate that which he sees from that which he "knows" is there, is able to draw perspectively correctly, without having ever learned perspective. The expert draughtsman needs the rules of perspective just as little as the philosopher or scientist the rules of formal logic.

[2] *Vide* Kirschmann, *Die Dimensionen des Raumes*, pp. 27 and 97 (Leipzig: Wilhelm Engelmann, 1902).

dependent upon the "double eye."[1] The purpose of binocular co-operation is not to give us the third dimension, but to facilitate the accurate measurement and comparison of distances.

In stereoscopic vision there are three elements which affect the completeness and mode of the combination of the impressions upon the two retinas. These are the similarity or dissimilarity of the two impressions, (1) spacially, i.e., in size, form and position-relations, (2) in quality of light sensations, or colour, (3) in intensity of light sensation, or brightness. When the two retinal impressions are exactly alike in all these respects the result is simple binocular combination; i.e., there is a single image, which has not the stereoscopic depth or distance effect, but is exactly similar to the monocular images, except in some cases in being brighter. (It is an interesting fact that there is no summation of saturations, as there is of intensities.) When the retinal images are *spacially* different there are two possibilities: (*a*) that though different in size, form, or position-relations they are stereoscopically combined into a single image with enhanced depth effect; (*b*) that they are so different as not to unite, in which case "double images" will result. Differences in *intensity* or *quality* of light between the two retinal images may result in a variety of ways. The images may combine; one may suppress the other; or there may appear the "competition" of the vision-fields, the images alternately replacing each other.

The object of the present investigation may in general terms be described as being to discover, (1) the limits of possibility of combination for images of different colour or bright-

[1] There are two views held with regard to the chief factor of monocular depth perception. The one claims that the muscular sensations which accompany the changes of accommodation are chiefly responsible for the perception of depth (Baird: *The Influence of Accommodation and Convergence upon the Perception of Depth*, in Am. Journ. of Psych., XIV, 150–200). The other view, which admits, of course, that accommodation is a factor, though a subordinate one, claims that the chief data for depth-perception in monocular vision are, for the near surroundings, furnished by the parallax of indirect vision. This latter view is strongly supported by the fact that in very important parts of the vision field, where binocular vision is excluded, we have distinct and sharp depth perception, absolutely independent of accommodation. (Kirschmann, *Die Parallaxe des indirekten Sehens und die spaltförmigen Pupillen der Katze*, in Philos. Stud. IX, 447-495.)

ness; (2) the relation to combination of contours and to stereoscopic depth of such differences in the colour or the brightness of the images upon the respective retinas. In such an investigation the question of intensity naturally comes first. For in stereoscopic combination the effect of the co-operation of the two eyes is three-fold: (1) the images are combined so as to present the appearance of a single surface; (2) with regard to contours, there are, as mentioned before, three possibilities, (*a*) that they coincide, (*b*) that they are incongruent, but combine into a single three-dimensional image, (*c*) that they do not combine ("double images"); (3) there is frequently, though not always, a change of brightness from that of the monocular images. Our first investigation, therefore, will be concerning the relative brightness of monocular and binocular vision.

II. COMPARISON OF MONOCULAR AND BINOCULAR INTENSITIES

This question of the relative brightness of monocular and binocular vision at once opens up some very interesting problems. By the earliest investigators it was found that the same object appears brighter when looked at with both eyes than when regarded with only one. Jurin, in 1755, fixed the relation as 13:12. Valerius, in 1873, by a more accurate method of investigation, showed that the increase or decrease of brightness by the admission or exclusion of the second eye varied, with different absolute intensities, from about $\frac{1}{10}$ to $\frac{1}{7}$, though Valerius himself did not think the absolute brightness had anything to do with the result. These early investigations are not very conclusive, first, because the methods of experimenting were not sufficiently accurate, secondly, because they ignore the fact that it is not physical intensities but intensities of sensation that are being compared, and hence neglect the subjective conditions which must affect the results. The investigations of Fechner and Aubert upon this point have established two facts. They proved that by placing before one eye a smoked glass which absorbs comparatively little light there may be produced as great a darkening of the common vision-field as is produced by a glass which absorbs very much more light. For instance, if the light admitted to the unobscured eye be represented by 1000, the total intensity

is the same when the other eye looks through a glass which admits 55 parts of light as when it looks through a glass which admits 500; while the admission of 100 parts of light to the second eye has about the same effect as the admission of 200. The points of equal darkening are called by them "conjugate points," and between these points lies what they designate as the "minimum point," or point of greatest darkening of the common vision-field by the obscuration of one of the eyes. When this point has been reached a decrease of the light admitted to the second eye has the same effect as an increase, viz., it increases the total brightness. They also showed that when one eye is partly obscured by a smoked glass or episkotister, the closing of that eye, or the total cutting off of the light from it, may result, under certain conditions, in a brightening of the common vision-field. This latter is the phenomenon known as "Fechner's paradox," the paradox consisting in the fact that a decrease in the intensity of physical stimulus is followed by an increase in the intensity of sensation. With this "paradox" as a starting point, some experiments were made by the writer for the purpose of clearing up somewhat this question of the relation of binocular and monocular intensities. Before referring to the results of these experiments, however, it is necessary to define more closely their object. There are two questions which do not seem to have been very clearly distinguished by previous investigators. One is the question to what extent an object appears brighter or darker according as it is regarded continuously under similar conditions with one eye or with two. Here we have to do with a continuous state in co-operation or non-co-operation. The other question is, how much intensity is added to that of monocular vision by the addition of the second eye, or subtracted from that of binocular vision by the closing of one eye. The point here is the immediate effect of a change. Looking at it from the former standpoint we have to seek for an equation between binocular and monocular intensities. From the latter standpoint the question presents itself as follows: for every intensity in monocular vision there exists a certain intensity, the admission or non-admission of which

to the other eye has *no effect* on the total intensity. To find for some cases these physical intensities, which, as regards the intensity of light sensation, are entirely ineffective, was the purpose of the experiments. Fechner's paradox (that if one eye is partially obscured by a smoked glass or similar means, the closing of that eye is followed by brightening of the whole visual field) had been found to occur only when a glass or episkotister was used which absorbed most of the light. On the other hand, if one were used which absorbed comparatively little light, on the closing of the partially darkened eye the whole visual field appeared darker. Between these limits, therefore, there must be, in analogy to Fechner's and Aubert's "minimum point," an indifference point, where no difference will appear in the brightness of the common visual field on the closing of one eye. That point, then, is what the experiments sought to discover.

The apparatus used and the method of experimenting have been fully described elsewhere.[1] The results, however, are of such importance for the present investigation as to warrant the reproduction of the tables here in a modified form.

TABLE I. OBSERVER K. LEFT SIDE.

Description of Light Used	Photometrically Determined Intensity	Amount of Light for the Second Eye Inefficient for the Brightness of the Common Vision Field		
		a. In Degrees of the Episkotister	b. In Units of Intensity	c. Ratio of the Intensity for the Other Eye
32 c.p. lamp + 2 sheets of white paper and 10 tissue papers	1	127½°	·35	·35
32 c.p. lamp + 10 t.p	12(?)	78°	2.60	.21
32 c.p. lamp + 6 t.p	120	68°	22.66	.18
32 c.p. lamp + 4 t.p	210	63°	36.75	.17
32 c.p. lamp + 2 t.p	360	52°	52.00	.14

[1] *Experiments on Fechner's Paradoxon*, (Am. Jour. of Psych., vii, 9-25.)

TABLE II. OBSERVER K. RIGHT SIDE.

Description of Light Used	Photometrically Determined Intensity	Amount of Light for the Second Eye Inefficient for the Brightness of the Common Vision Field		
		a. In Degrees of the Episkotister	b. In Units of Intensity	c. Ratio of the Intensity for the Other Eye
32 c.p. lamp + 2 sheets of white paper and 10 tissue papers	1	132½°	.36	.36
32 c.p. lamp + 10 t.p	12(?)	107°	3.56	.29
32 c.p. lamp + 6 t.p	120	77°	25.66	.21
32 c.p. lamp + 4 t.p	210	73°	42.58	.20
32 c.p. lamp + 2 t.p	360	68°	68.00	.18

TABLE III. OBSERVER R. AVERAGE OF LEFT AND RIGHT SIDES.

Description of Light Used	Photometrically Determined Intensity	Amount of light for the second eye inefficient for the brightness of the common vision field.		
		a. In Degrees of the Episkotister	b In Units of Intensity	c. Ratio of the Intensity for the Other Eye
32 c. p. lamp + 2 sheets of white paper and 10 tissue papers	1	165°	.45	.45
32 c.p. lamp + 10 t.p	12(?)	122°	4.06	.33
32 c.p. lamp + 6 t.p	120	100°	33.33	.27
32 c.p. lamp + 4 t.p	210	77°	44.91	.21
32 c.p. lamp + 2 t.p	360	64°	64.00	.17

Examination of Tables I-III will show that the results of the experiments which are significant for the present inquiry are two:

(1) The first is the dependence upon the absolute intensity of the proportion of the full light which can be admitted to the second eye without effect upon the total brightness. This dependence appears throughout the tables in such an obvious and regular manner that it is surprising that it has escaped the notice of previous investigators. But as regards the relative intensities of monocular and binocular vision, this dependence means that the ratio of those intensities to each other cannot be exactly determined, because it is not a con-

stant ratio. It varies with the absolute intensity. For small absolute brightness the proportion of the light admitted to the second eye without increasing the total brightness is much greater than for higher intensities.

(2) The second fact of especial interest is that the proportion of the full light which can be admitted to the second eye without effect upon the brightness of the common visual field is in all cases so large. The proportion, according to the above tables, varies from about one-seventh to nearly one-half, with different observers and under different conditions. In some subsequent experiments, it was found that with lower absolute intensities the proportion was more than one-half.

The bearing of the first of these results upon the theme of our inquiry will be more apparent when we come to discuss the relation of light intensity to stereoscopic depth perception. At present the second result seems to possess more direct interest. The reason (apart from the operation of Weber's law) for the relatively slight effect of the light admitted to the second eye upon the brightness of the common visual field is of course that the purpose of the co-operation of the two eyes is not to increase the brightness, but to accomplish those parallactic relations which are the principal means of binocular depth perception. The question at once suggests itself, however,—is the amount of light in the second eye, which is ineffective as regards the total brightness, the same as the least amount necessary for the stereoscopic combination of the two retinal images? Thus we come to the second step in our investigation.

III. THE RELATION OF INTENSITY OF LIGHT SENSATION TO THE STEREOSCOPIC PERCEPTION OF DEPTH

This branch of the subject has also been investigated by an experimental method which is fully described in an earlier publication.[1] Those experiments had for their object to determine the least amount of light which must be admitted

[1] *Light Intensity and Depth Perception.* (Am. Jour. of Psych., vol. VII, pp. 518-532.)

to the second eye in order to produce the stereoscopic effect, and to find whether or not that amount is the same as the amount of light which in the second eye is inefficient as regards the comparative light intensities of monocular and binocular vision. As in the present papers some further experiments upon this point, both with colourless and with coloured light, will be reported, the tabulated results of the former experiments are inserted here for the purpose of comparison.

TABLE IV.—OBSERVER R.

Description of Light Used	Photometrically Determined Intensity	Amount of Light in the Second Eye Necessary						Amount of Light in the Second Eye which has no Effect on the Brightness of the Common Visual Field		
		I. For Complete Stereoscopic Effect			II. For Any Stereoscopic Effect					
		a. Opening of the Disc in Degrees	b. Units of Intensity	c. Ratio of the Light in the Other Eye	a. Opening of the Disc in Degrees	b. Units of Intensity	c. Ratio of the Light in the Other Eye	a. Opening of the Disc in Degrees	b. Units of Intensity	c. Ratio of the Light in the Other Eye
8 c. p. lamp + 34 sheets of tissue paper	1	147½	.41	.41	85	.18	.18	151	.41	.41
8 c. p. + 26 t. p	2.77	85	.65	.23	48½	.37	.13	158	1.21	.43
8 c. p. + 20 t. p	3.88	65	.70	.18	32½	.35	.09	156	1.68	.43
8 c. p. + 16 t. p	6.66	66¾	1.31	.19	30½	.55	.08	175	3.23	.48
8 c. p. + 12 t. p	16.16	47½	2.09	.12	14	.64	.03	197	9.12	.56
8 c. p. + 8 t. p	29.16	32	2.59	.08	10⅜	.85	.02	175	14.17	.48
8 c. p. + 4 t. p	56.94	19½	3.04	.05	5½	.90	.01	174	27.51	.48
8 c. p.	100.00	12½	3.47	.03	2¾	.74	.007	145	38.20	.38
16 c. p.	192.00	10⅜	5.53	.02	1½	.80	.004	127	67.69	.35
32 c. p. + 4 t. p	527.70	12	17.59	.03	¾	1.09	.002	103	145.91	.27
32 c. p.	1014.80	5	14.09	.01	*5/12	1.10	.001	117	330.54	.32
50 c. p.	1515.70	3⅓	14.03	.009	*¼	2.80	.001	91	381.93	.25
100 c. p.	3130.40	5⅓	46.39	.01	*⅓	2.17	.0006	83	719.98	.22

*These figures represent the averages of a number of cases in some of which a partial effect remained with a smaller opening than the disc was graduated to measure exactly; the minimum point was, in those cases, taken as 0.

TABLE V.—OBSERVER L.

Description of Light Used	Photometrically Determined Intensity	Amount of Light in the Second Eye Necessary						Amount of Light in the Second Eye which has no Effect on the Brightness of the Common Visual Field		
		I. For complete Stereoscopic Effect			II. For Any Stereoscopic Effect					
		a. Opening of the Disc in Degrees	b. Units of Intensity	c. Ratio of the Light in the Other Eye	a. Opening of the Disc in Degrees	b. Units of Intensity	c. Ratio of the Light in the Other Eye	a. Opening of the Disc in Degrees	b. Units of Intensity	c. Ratio of the Light in the Other Eye
8 c. p. lamp + 34 sheets of tissue paper	1	225	.62	.62	114	.31	.31	230	.63	.63
8 c. p. + 26 t. p.	2.77	176 2/3	1.35	.48	42	.32	.11	169	1.26	.45
8 c. p. + 20 t. p.	3.88	102	1.02	.26	26 2/3	.28	.07	177	1.91	.49
8 c. p. + 16 t. p.	6.66	93 1/3	1.72	.25	16 2/3	.30	.04	157	2.89	.43
8 c. p. + 12 t. p.	16.16	80	3.59	.22	9 2/3	.43	.02	176	7.21	.44
8 c. p. + 8 t. p.	29.16	34 1/6	2.76	.09	10	.83	.02	174	14.07	.48
8 c. p. + 4 t. p.	56.94	42 1/2	6.70	.11	4 1/2	.67	.01	186	28.52	.50
8 c. p.	100.00	28 1/3	7.87	.07	2 1/6	.78	.007	190	52.77	.52
16 c. p.	192.00	22 1/2	12.00	.06	1 1/3	.89	.004	147	78.28	.40
32 c. p. + 4 t. p.	527.70	5	7.32	.01	1/2	.73	.001	†98	142.91	.27
32 c. p.	1014.80	7	19.73	.01	*1/4	.73	.0007	190	537.75	.52
50 c. p.	1515.70	8 1/6	37.36	.02	*1/6	.84	.0005	156	657.50	.43
100 c. p.	3130.40	15 3/4	136.95	.04	*1/8	7.61	.0002	173	1505.58	.48

*Sometimes the effect did not wholly disappear with the least amount of light that could be admitted.
†Result of only one series.

TABLE VI.—OBSERVER K.

Description of Light Used	Photometrically Determined Intensity	Amount of Light in the Second Eye Necessary						Amount of Light in the Second Eye which has no Effect on the Brightness of the Common Visual Field		
		I. For Complete Stereoscopic Effect			II. For any Stereoscopic Effect					
		a. Opening of the Disc in Degrees	b. Units of Intensity	c. Ratio of the Light in the other Eye	a. Opening of the Disc in Degrees	b. Units of Intensity	c. Ratio of the Light in the other Eye	a. Opening of the Disc in Degrees	b. Units of Intensity	c. Ratio of the Light in the other Eye
8 c. p. lamp + 34 sheets of tissue paper.....	1	110	.30	.30	70	.19	.19	†?		
8 c. p. + 26 t. p.....	2.77	63	.45	.16	47	.36	.12	164	1.44	.50
8 c. p. + 20 t. p.....	3.88	50	.53	.13	31	.33	.08	166	1.79	.46
8 c. p. + 16 t. p.....	6.66	29	.55	.08	14	.25	.03	180	3.33	.50
8 c. p. + 12 t. p.....	16.16	23	1.03	.06	9	.40	.02	172	7.73	.47
8 c. p. + 8 t. p.....	29.16	15	1.21	.04	3	.24	.008	246	19.92	.62
8 c. p. + 4 t. p.....	56.94	15	2.37	.04	3½	.55	.009	171	27.02	.47
8 c. p.....	100.00	11	3.05	.03	2½	.69	.006	132	36.57	.36
16 c. p.....	192.00	11½	6.13	.03	¼	.26	.001	148	79.11	.41
32 c. p. + 4 t. p.....	527.70	2½	3.66	.006	½	.73	.001	135	197.88	.37
32 c. p.....	1014.80	3	8.45	.008	*¼	.70	.0006	114	320.88	.31
50 c. p.....	1515.70	2	8.42	.005	*0(?)			129	541.32	.35
100 c. p.....	3130.40	1¼	10.86	.003	*0(?)			107	926.49	.29

*Opening could not be made small enough to completely destroy stereoscopic effect.
†Light too dim and too much orange colour from the tissue papers for discrimination.

TABLE VII.—OBSERVER A.

Description of Light Used	Photometrically Determined Intensity	Amount of Light in the Second Eye Necessary						Amount of Light in the Second Eye which has no Effect on the Brightness of the Common Visual Field		
		I. For Complete Stereoscopic Effect			II. For any Stereoscopic Effect					
		a. Opening of the Disc in Degrees	b. Units of Intensity	c. Ratio of the Light in the other Eye	a. Opening of the Disc in Degrees	b. Units of Intensity	c. Ratio of the Light in the other Eye	a. Opening of the Disc in Degrees	b. Units of Intensity	c. Ratio of the Light in the other Eye
8 c.p. + 16 t.p..	6.66	112	2.07	.31	32	.59	.08	*192 (?)	3.55	.53
8 c.p. + 12 t.p..	16.16	90	4.04	.25	22½	1.01	.06	*231 (?)	9.87	.61
8 c.p. + 8 t.p...	29.16	110	8.91	.30	32½	2.63	.08	217	17.59	.60
8 c.p. + 4 t.p...	59.94	90	14.23	.24	25	3.95	.06	187	29.61	.52
8 c.p.....	100.00	22	6.11	.06	9	2.50	.02	98	27.31	.27
16 c.p.....	192.00	22	11.73	.06	9	4.80	.02	131	70.00	.36
32 c.p. + 4 t.p..	527.70	55	75.06	.14	1	1.46	.002	116	243.08	.46
32 c.p.....	1014.80	9	25.37	.02	3	8.45	.008	109	306.55	.30
50 c.p.....	1515.70	10	42.10	.02	1½	6.31	.004	*210 (?)	884.15	.51
100 c.p.....	3130.40	50	434.77	.13	½	4.34	.001	88	761.10	.24

*The "equal" limits had not been passed at 270°, more than which the sectors of the disc would not admit.

Remarks on the Tables: (1) Division I of the tables shows the lowest point for each absolute intensity at which the stereoscopic effect was complete, Division II the point at which it had entirely ceased. Between these points there was a region of partial or incomplete combination. Here the outlines were sometimes confusedly intermingled, sometimes the complete stereoscopic effect would alternately appear and disappear, and again there would occur the phenomenon of the competition of the vision-fields, first one and then another set of lines becoming distinct.

(2) In the last division of the tables, which gives for each absolute intensity the amount of light which can be admitted to one eye without producing any change in the brightness of the common vision-field, it will be observed that the results are less regular than in Tables I-III in the preceding section. But that is probably because these results represent the averages of a smaller number of trials. The judgments concerning light intensity are more difficult than those regarding the stereoscopic effect.

(3) All the results are slightly less regular with the highest intensities used, owing probably to those intensities being somewhat near the "upper limit" for the eyes adapted to the darkened room.

(4) Where fractions of degrees are given under "Opening of the disc" these are the result of averaging a number of cases. The disc was not graduated to measure less than half a degree with accuracy. In Tables I-III such fractions are not given, but when less than $\frac{1}{2}$ are disregarded, when more than $\frac{1}{2}$ are counted as 1°.

Summary of Results: (1) The amount of light in the second eye necessary to produce the stereoscopic effect varies, like the minimum of light required to increase the total brightness, in fairly regular correspondence with the absolute intensity. The correspondence is not such as to establish a proportionality between the quantities in question, but the amount, except with the highest intensities used, quite regularly be-

comes greater or less as the absolute intensity increases or diminishes.

(2) The amount of light required in the second eye to produce the stereoscopic effect seems, with most of the intensities used, surprisingly small. With very high intensities $\frac{1}{100}$ of the full light or less was sufficient to make the effect complete, while in many cases a partial effect remained with the very least amount which the disc could be adjusted to admit (estimated at $\frac{1}{1000}$ or less). On the other hand, with the lowest absolute intensities, about $\frac{1}{2}$ of the full light was necessary for the second eye in order to produce the complete stereoscopic effect, while for any effect at all, from about $\frac{1}{4}$ to $\frac{1}{8}$ of the full light was required.

(3) There is in all cases a noticeably wide range between the point where the objects begin to combine, and the point where the complete stereoscopic effect is obtained. The amount of light at the latter point is about from two to twenty times as great as at the former. Thus in Table V, with the absolute intensity 1, an opening of the episkotister disc of 225° is required for the complete stereoscopic effect, while a partial effect appears above 85°. With the absolute intensity 192 in this table a partial effect appears above $1\frac{5}{8}$°, while for the full effect $22\frac{1}{2}$° was required. And in the other tables the case is similar.

(4) The "indifference point," or point of inefficiency as regards the comparative light intensities of monocular and binocular vision, varies also, as in the experiments on intensity referred to in the preceding section, in correspondence with the absolute intensity; the amount of light which can be admitted to the second eye without affecting the brightness of the common visual field increases with the increase of absolute intensity. The ratio of the amounts of light admitted to the obscured and the unobscured eyes shows, however, at this indifference point less variation than at the lowest point of effectiveness for the stereoscopic combination. It is noticeable also that while the amount of light for the second eye inefficient for the brightness of the combined visual field

increases in quite regular correspondence with the absolute intensity, the increase here, as with the light required in the second eye for the stereoscopic effect, is not proportional; for while the actual amount of light increases, the ratio to the full light continually decreases.

(5) The "indifference point" of light intensity and the lowest point of effectiveness for the stereoscopic effect do not coincide. The indifference point is very much higher in nearly all cases than the point below which the stereoscopic effect ceases to be good. The points approach nearer to each other, the lower the absolute intensity; but there is a region, which with higher absolute intensities becomes very great, where the "paradox" of Fechner occurs, while yet the stereoscopic effect is completely preserved.

Have we now in these results any data for the solution of the problem which emerged from our investigation regarding the relative intensities of monocular and binocular vision viz., that so large a proportion of the full light can be admitted to the second eye without producing any effect upon the total brightness? That there is something more involved here than the general quantitative relation of stimulus and reaction i.e., Weber's law, is apparent from the fact that the proportion changes with the changing of the absolute intensity. The fact that the chief purpose of the two eyes is not to increase the brightness, but to establish those parallactic relations upon which binocular depth perception depends, suggests an easy solution of this problem. So much of the light admitted to the second eye goes to produce the stereoscopic effect, and the remainder, subject of course to Weber's law, to increase the total brightness. Our tables, however, show that the lowest point where the stereoscopic effect is produced is not the same as the "indifference point" of light intensity except in one or two cases, where their coincidence may be accidental In nearly all cases the least amount of light required for the stereoscopic effect is less—sometimes a hundred times less—than the amount which is inefficient for the brightness of the common visual field.

A second question is whether our results throw any light upon Fechner's "paradox." Here also, prior to any experimental test, it might be thought that the explanation is quite simple. We have but to assume that where the "paradox" occurs it is due to the fact that the physical energy which reaches the retina of the partially obscured eye is less than is necessary to enable that eye to play its part in forming the combined impression and localizing it in the third dimension, and that in that case part of the energy of the free eye is subtracted to aid the other eye in the binocular combination (not, of course, the stereoscopic combination); then on the closing of the other eye, this part of the energy would be set free and the result would be an increase of the light intensity. To confirm this suggestion also, however, the results should show a practical coincidence of the indifference point of light intensity and the lowest point of effectiveness for the stereoscopic combination. Whereas, as we have seen, the indifference point is very much higher in nearly all cases than the point below which the stereoscopic effect ceases to be good; in other words the paradox occurs over a considerable region where the stereoscopic effect is complete.

With regard to Fechner's and Aubert's "minimum" and "conjugate points," our results have not much contact with the results of those investigators. They fixed the minimum point, i.e., the point of greatest darkening in the common visual field by the darkening of one eye definitely at the point where, the full light being represented by 1000, 122 represented the amount admitted to the partially-obscured eye. In our results, however, it appears: (1) that the ratio to the full light of the light required for the second eye to produce any effect on the total intensity is not a constant ratio, but varies with the absolute intensity; (2) that the indifference point is not usually a single definite point, but that there is commonly a considerable region within which no difference in the brightness of an object in the common visual field is observed when the object is regarded alternately with one eye and with two. The figures in the tables represent simply the averages of all

the equal cases. Some suggestions for a possible explanation of these results will be given in the next section.

Let us now revert for a moment to the second of the above-mentioned results, viz., the exceedingly small proportion of the full light which one eye may receive without the stereoscopic effect being destroyed or impaired. It might be thought that the result, in the experiments above referred to, was at least partially due to the very simple character of the outline drawings employed. Would the results have been similar had more complicated figures been used? That is a question somewhat difficult to investigate, because figures suitable for the purpose are not easily obtained. Ordinary stereoscopic photographs, for instance, will not do. For these have, even when regarded with one eye only, a certain depth effect, due to secondary factors of depth perception, from which it is difficult to abstract in judging of the stereoscopic effect. The solution of this difficulty was suggested by an article of Fuchs.[1] Dr. Fuchs refers to the experiments of Helmholtz[2] with tapestry patterns, etc., and of Meyer[3] with objects such as wire screens, etc. Both these authors reported that by convergence of the lines of regard of the two eyes upon a point nearer to or further from the observer than the plane of the objects observed, certain parts of the pattern could be seen stereoscopically, i.e., superimposed upon one another, and at different distances from the eye, so that certain figures in the pattern seemed to be, as it were, suspended in the air before the others. Fuchs, however, pointed out that convergence or squinting would not produce the stereoscopic effect so long as the superimposed double images held exactly the same relative positions in the two eyes. This can be seen by reference to Fig. 1, where convergence results in the appearance of four or more rings in each row, which, however, are all in the same plane. The stereoscopic effect

[1] *Ueber die stereoskopische Wirkung der sogenannten Tapetenbilder* (Zeitschrift fur Psychologie und Physiologie der Sinnesorgane, Bd. 32, Heft 2, 1903).

[2] *Handbuch der physiologischen Optik*, p. 799 (1896).

[3] Rosers und Wunderlichs *Archiv für die physiologische Heilkunde*, 1841, I, 316 etc.

reported by earlier authors must therefore, according to Fuchs, be due to the repetition of the figures in the pattern not being exactly regular, so that the distance of identical points, and consequently the convergence conditions required for corresponding parts, are different. He employed, to demonstrate this, a complicated drawing, consisting of very simple and exactly similar parts, in the arrangement of which, however, such irregularities are purposely introduced in a somewhat exaggerated degree. This drawing is reproduced in Fig. 2 (Fuchs' Fig. 3). This figure appeared admirably suited to our purpose. It is a much more complicated one than the others employed in our experiments, and has very little in itself to suggest the perception of depth, but on the contrary requires special conditions and effort—unless the eyes are assisted by glasses—in order to be seen stereoscopically. Some experiments were accordingly made with copies of this figure of Fuchs' as objects to see if our results would be confirmed when such objects were substituted for the simpler ones used in the former experiments. The same apparatus could not be used as in the other experiments, because the visual angle subtended by the objects was greater than was provided for by the openings in the front screen, and the divisions between the double openings would conceal parts of the drawings. Accordingly, the apparatus used was a modification of the simpler one designed for the experiments in regard to the relative intensities of monocular and binocular vision. The lamps used were in this case fixed above and in front of the objects, and screened so as to prevent their light shining directly into the observer's eyes. In some cases the experiment was performed by squinting, without any glasses over the openings through which the eyes looked. In others, convergence was facilitated by the use of lenses, which were attached in such a way that they could be pushed aside when not in use. The results, as exhibited in Tables VIII and IX, completely confirm those given in the former tables. For the second eye $\frac{1}{360}$ of the full light was usually sufficient to give at least a partial stereoscopic effect, and with from $\frac{1}{180}$ to $\frac{1}{60}$ the effect was complete.

TABLE VIII.—OBSERVER K.

Left Side				Right Side			
Illumination	Convergence	Opening of Disc	Stereoscopic Effect	Illumination	Convergence	Opening of Disc	Stereoscopic Effect
50 c.p.	Further away than plane of object..	*2°	Perfectly preserved.....	50 c.p.	Further.	*2°	Perfect.
"	"	1°	Slightly impaired.....	"	"	1°	"
"	Nearer than plane of object.....	*2°	Fairly good.....	"	Nearer.	*2°	"
"	"	1°	Not so good as with further convergence.....	"	"	1°	Impaired.
8 c.p.	Further.....	*2°	Not quite good.....	8 c.p.	Further.	*2°	Perfect.
"	"	1°	Partial and inconstant.....	"	"	1°	Fair—inconstant.
"	Nearer.....	*2°	Not quite perfect.....	"	Nearer.	*2°	Not quite good—rings have a penumbra.
"	"	1°	Traces only on part of drawing	"	"	1°	Only a trace.

* In all cases the effect was perfectly preserved with any wider opening than 2°.

TABLE IX.—OBSERVER R.

Left Side				Right Side			
Illumination	Convergence	Opening of Disc	Stereoscopic Effect	Illumination	Convergence	Opening of Disc	Stereoscopic Effect
8 c.p.	Further.	6°	Perfect	8 c.p.	Further.	2°	Completely preserved.
"	"	4°	Imperfect	"	"	1°	Fairly good.
"	"	2°	Slightly Impaired				
"	"	1°	Almost complete	"	Nearer.	2°	Completely preserved.
"	Nearer.	6°	Perfect				
"	"	4°	Good, but unsteady	"	"	1°	Very slight.
"	"	2°	Only a trace—much confusion				
"	"	1°	None				

IV. BINOCULAR SYNERGIES

In connection with previous reports of the writer's experiments[1] certain suggestions were made first by Professor Kirschmann and afterward developed more fully by the writer as to a possible explanation of certain phenomena of binocular co-operation, and particularly of Fechner's paradox. These were characterized by Professor A. Binet[2] as "bien hypothétiques." Their hypothetical character is, however, no disparagement, inasmuch as they were not meant, as Professor Binet apparently regarded them, as interpretations of the writer's results, but rather as tentative suggestions, the further questions to be investigated before any strong claim could be advanced for them being at the same time pointed out. The intimate character of the co-operation of the two retinas which our provisional explanation of the "paradoxical" phenomenon, especially, presupposes is such, however, as to raise the whole question of the reaction of one retina upon stimuli applied to the other; and it may, therefore, not be out of place to give briefly the gist of previous investigations and discussions of this subject. That having been done, the re-statement of the above mentioned suggestions regarding the phenomena of binocular co-operation and binocular intensities may be found to have some bearing on the question of the retinal transference of impressions.

That it is possible, under certain conditions, by the stimulation of one retina to produce an impression in the other, has been maintained by various investigators, from the time of Newton. Titchener, who has made elaborate series of experiments upon several phases of the problem, gives also in his article a comprehensive summary of previous discussions.[3] A further discussion is given by Franz.[4] Against the assumption of a functional interconnection of the retinas two positions

1 Am. Jour. of Psych. vol. VII., 1895, pp. 9-25, 518-532.

2 L'Année Psychologique, 1896, p. 381.

3 *Ueber binoculare Wirkungen monocularer Reize.* (Philos. Stud. VIII, 1893, pp. 231-310.)

4 *After Images* (Psych. Review, Mon. Sup. 12, 1899).

have been advanced, that in the cases adduced no real transference takes place, and that it is not the retina of the unstimulated eye, but the brain centre that is affected.

To the second of these claims very little importance in the present stage of the question need be attached. For how is the matter simplified by assuming that in certain cases the stimulation, say of the right retina, produces the same molecular activity in the visual cerebral centre usually produced by the stimulation of the left retina, rather than that in those cases an activity is started in the left retina by the stimulation of the right? The position that the impression is mistakenly referred to the unstimulated eye but that there is no real transfer of activity from one eye to the other is favoured by Franz. He supports it by the result of an experiment in which the light stimulus was applied to the portion of the right eye which corresponds to the blind spot of the left eye. On opening the left eye an image appeared. But since with the portion of the left eye corresponding to the stimulated part of the right, nothing can be seen, the conclusion is that the transfer in this case cannot be real, and, therefore, may not be in other cases. This does not, however, seem conclusive. For with the closed eye there is no question about the direction of light rays entering it, the question is whether the starting of a certain activity in one eye by an appropriate stimulus may be followed without direct stimulation by a similar activity in the other. Delabarre[1] had before come to the same conclusion, on account of the image apparently in the unstimulated eye changing or disappearing with a change in the objective conditions of the eye which received the stimulus. Against this are the results of Fechner[2] regarding binocular contrast, in which the one eye, while darkened or receiving only faint grey light, saw the complementary of the colour simultaneously presented to the other eye. That the transfer is real is also held by Titchener, the results of whose

[1] *The Seat of Optical After-Images.* (Am. Jour. of Psych., vol. II, 1889, pp. 326 etc.)

[2] *Ueber einige Verhältnisse des binocularen Sehens.* (Abh. d.k. Säch. Ges. d. Wiss., VII, 481, 1860.).

experiments showed marked differences between the images in the respective eyes with regard to duration, brightness, and changes of colour.

The results of our experiments, reported in the preceding section, touch the present discussion at two points:

1. The amount of light admitted to the second (the less stimulated) eye at the point where the objects begin to combine is but a small fraction of that required for the complete combination. This could easily be explained if we might assume that a part of the physical energy communicated to the retina of the unobscured eye is subtracted, when necessary, to aid the other eye in the binocular combination. Of course the factors of binocular depth perception are such that in it one eye cannot do any part of the work of the other. But for the production of the stereoscopic effect it is first necessary that the two retinal impressions should be combined so as to produce the impression of a single surface. This distinction of the simple binocular from the complete stereoscopic combination is not a merely hypothetical one. Throughout the experiments it was frequently noted that the surfaces would coincide where there was no depth perceptible. Now if where the objects begin to combine there is only the combination into a single surface, and in that the free eye can more largely aid the other, while in the complete stereoscopic combination the aid it can give is proportionately much smaller, that may account for the proportion of light required in the second eye in the latter case being enormously greater than where the objects combine only as a single surface.

2. The second point concerns the suggested explanation of the paradox of Fechner, that its occurrence is due to the energy communicated to the partially-obscured eye being too little to enable that eye to play its part in combining the images. Part of the energy communicated to the free eye is subtracted to aid the other, and the result is a darkening of the common field of vision. Then on the closing of the other eye that part of the energy of the free eye is liberated, and the common field becomes brighter. This suggestion seems to be negatived

by the fact that the amount of light in the partially-obscured eye which has no effect upon the total brightness is very much greater than the amount required for the stereoscopic effect. The lower the absolute intensity, however, the nearer these amounts approach to each other, and at certain extremely low intensities they coincide. If this be taken as an indication that the explanation holds good for these low intensities, the question of course at once arises—why not for higher intensities? There is even for these, on the assumption of a functional interrelation of the retinas, a possible explanation, which is given here rather than in the discussion in the preceding section, because it can only be hypothetical until this whole question is more thoroughly cleared up. Let us assume that with the extremely low intensities in question the light which reaches the retina of the unobscured eye is only about enough to enable that eye to play its own part in the binocular combination. For example, where in Table IV the absolute intensity is 1, the light which must be admitted to the second eye to produce the complete stereoscopic effect is represented by .41, and .41 also represents for the absolute intensity 1 the amount of light in the second eye which has no effect on the brightness of the common visual field. If, therefore, less light than .41 is admitted to the second eye, we shall have the paradox and at the same time stereoscopic combination will be absent or only incomplete. This is perhaps because the stimulus applied to the second eye in this case is not sufficient to produce the energy required for the stereoscopic effect. Part of the energy may be subtracted from the other eye to aid in the binocular combination, and consequently the common visual field is darkened. But because the light admitted to the free eye is little more than the least amount needed to produce the required effect in it, while that eye continues to discharge its function there cannot be sufficient energy withdrawn from it to make up what is lacking in the other eye, and hence the stereoscopic effect remains incomplete. Then taking a higher absolute intensity, let us say that represented in the table by 100, we find that the amount of light required

in the second eye for the complete stereoscopic effect is 3.47, while the amount inefficient for the brightness of the combined visual field is 38.20. On the above suggested theory it might be held that the energy which reaches the retina of the free eye is in this case more than the least amount required for that eye to play its part in the co-operation of the two eyes, and where the other eye does not receive sufficient for that purpose, enough energy may be subtracted from the free eye to supplement that of the partially obscured eye and produce the complete stereoscopic effect. This would account for the fact that with all but the lowest intensities there is a region, growing more extended as the absolute intensity increases, where the paradox occurs, while yet the stereoscopic effect is completely preserved.

Our results, then, favour the view of a functional interconnection of the retinas to the extent that certain phases of them, otherwise unexplained, seem capable of explanation on this theory. Yet these results are by no means conclusive. It may yet be found that all the phenomena in question are not due to either retinal or cerebral processes, but are purely psychical.

V. LUSTRE.

1. *Theory of Lustre.* The phenomenon of lustre is discussed in connection with the problem of intensity because, although intensity is only one of the factors in the production of this phenomenon, the part which it plays is sufficiently important to warrant a careful investigation of its influence. Since, however, several of the authors who deal with this subject are not free from error or confusion regarding the importance of intensity or of intensity-contrast as a condition of the phenomenon of lustre, it is necessary, in the beginning, to devote a little space to clearing up this point.

Most of the investigators of the subject hitherto have not distinguished the physical and the psychological aspects of the matter with sufficient clearness. For the physicist the questions raised concern the movement processes which take

place in the reflection of light from surfaces under different conditions. For him the character of the sensation of sight is of interest only as indicating what physical process is going on. And if the characteristics of our light sensations were entirely different from what they are, that would not change the nature of the physicist's problem in the least. The psychologist, on the other hand, has to deal with what takes place in consciousness. For him the question is "What are the qualities or intensities or space and time relations of the sensations or complexes of sensation which take part in the impression of lustre?" And for the psychologist, therefore, the physical properties of the light are of only conditional importance. Failure to observe this distinction has led to much confusion of thought. Hering, for example, in common with several other writers, regards lustre as dependent upon high intensity. Now the intensity which can be a factor in the perception of lustre must be the intensity of light sensation. Yet Hering speaks of the lustre which belongs to self-luminous bodies as well as of that which appears on incompletely mirroring surfaces. But to be self-luminous is not a property of objects which is directly given to the sense of sight. To decide whether a body is self-luminous we must have other data than those which the sense of sight furnishes. Thus, for instance, it is quite easy to illuminate a red or orange paper in the daytime in such a manner that it looks exactly like a red-hot iron. Everybody has noticed, too, how impossible it is to decide, at the time of a brilliant sunset, whether the ruddy glow seen at certain windows is caused by a light or a fire within, or is simply the reflection of the sunshine. A very interesting, as well as very decisive experiment in this line has been made quite incidentally in the use of Professor Kirschmann's apparatus for obtaining spectrally pure light in larger surfaces. This apparatus is arranged so as to effect a two-fold selection of the rays; a surface which reflects one part of the spectrum chiefly is illumined by light which has passed through absorbing media of the opposite selective preference. The apparatus has been used by Messrs. Lane,

Baird and Richardson, and Miss Emma S. Baker, and i described in their articles in the University of Toronto Studies Psychological Series. It shows a square, or two squares, on in the middle of the other, of light of high spectral saturation and in any intensity desired. Observers who know nothin of the arrangement for the production of these colours ar absolutely unable to say whether they see reflected light transmitted light, or the source of light itself. This has bee especially conspicuous in the experiments of Messrs. Hughe and Armstrong, to be elsewhere reported, in which only colour less light was employed. Certain observers, in order that the might be in complete ignorance of the instrumental arrange ment, were brought blindfolded to the entrance of the observa tion tube. These actually did not realize that they were lookin through a diaphragm of varying aperture, but thought the saw self-luminous or transparent objects. And they wer moreover not sure whether the size of the object increase and decreased or whether its distance was changed. Suc distinctions, then, as that of Hering referred to above denot a confusion of the physical properties of light with the char acteristics of our light sensations. And it is just this confusio that prevents both Aubert and Hering from seeing that some thing more than brightness or brightness-contrast is require for lustre. Psychically there is not such a thing as light sensa tions of different quality or intensity which are coinciden in both space and time. If several light stimuli of differen quality and intensity are applied simultaneously to the sam retinal points the accompanying sensation is always simpl and single. Only when either spacially or temporally separ ated are the impressions not so combined. Wundt[1] first i 1861 showed conclusively that the characteristic of lustre whether monocular or binocular, is incomplete mirroring i.e., a combination of mirror reflection and diffuse light which combination depends on the parallactic relations arisin from movements of the eye or from binocular combination o

[1] *Ueber die Entstehung des Glanzes.* (Poggendorf's Annalen, Band 116 s. 627 etc.)

images upon the two retinas. Both these parallactic relations (of the "double eye" and the moved eye) involve the third dimension, and the great contribution made by Wundt's work to the subject lay in showing that the space relations which are adequate for the explanation of lustre must be three-dimensional. Wundt shows also that strong contrast, whether of quality or intensity, favours the phenomenon.

The relation of differences of brightness to the phenomenon of lustre has been further elucidated by Kirschmann[1] who distinguishes the genuine or parallactic lustre from an apparent or false lustre, the latter consisting in certain brightness relations which are unusual in pure diffuse reflection, but commonly accompany the true or parallactic lustre. If we have two bodies with level upper surfaces, one of which is lustrous and the other is not, the former will from one direction appear brighter, from all others darker than the latter. If the surfaces are curved, there will be more than one direction from which the lustrous body appears brighter than the non-lustrous. But then also there will be adjacent parts of the curved lustrous surface which present differences of brightness such as do not occur on the dull surface, under the same conditions of illumination. Now having from experience learned that a continuously curved dull surface does not present strong contrast of intensity in constant illumination; if we see on a surface brightnesses near each other, such as according to our experience cannot occur on a dull surface, and if we are not upon any other ground doubtful about the spacial conditions, we conclude that there cannot be only diffuse light present, but that the surface is lustrous. But this apparent lustre can be produced artificially, apart from any parallactic relations, by suitably illuminating the single parts of the surface independently of each other. Painters also, provided that the brightness differences of the lustrous bodies which they reproduce upon the canvas are not too great, can succeed to a certain extent in painting lustre. Really, it is only the accidental sign of

[1] *Der Metallglanz und die Parallaxe des indirecten Sehens.* (Philos. Studien, XI, 147.)

lustre, the brightness-contrast, which the painter puts on the canvas. But the beholder, in whose experience this sign has been the almost invariable accompaniment of the true lustre, supplies what is lacking from his imagination. These brightness relations, therefore, though regarded by Aubert, Brücke and others, as the characteristic sign of lustre, are in reality only an accidental accompaniment of it.

To complete the account of the factors of the perception of the various kinds of lustre phenomena further reference must be made to the above-cited work of Kirschmann on metallic lustre. Former writers had identified metallic with binocular lustre. This is expressly done by Aubert.[1] Metallic lustre, however, is perceived quite as well with one eye as with two. Moreover, in the stereoscopic combination of photographs there is never any trace of metallic lustre, even where the binocular lustre is most perfect. This is very strikingly shown in the accompanying stereoscopic picture (Fig. 3). When stereoscopically combined, the picture shows the lustre of porcelain, of wax, of glass, of water, of a mirror, of polished wood, and even the surface lustre of metallic objects, but no metallic lustre. It might be objected that a stereoscopic reproduction on paper has not intensity enough for metallic lustre. But the same photograph has been used with the same result in diapositives, and by Professor Kirschmann's method of exhibiting stereoscopic pictures in transmitted light of great intensity, superposed on a semi-transparent screen. (The screen is a large plate of ground glass, and the double lantern is on the opposite side from the observer, who combines the two pictures by the usual means of a pair of spectacles with red and green absorbing glasses.)

The fact that metallic lustre depends on conditions of monocular vision might be regarded as excluding it from the range of our discussion. But there are two reasons against its exclusion, first, that by earlier writers it was considered as at most a special case of binocular lustre; secondly and chiefly, that the factor to which it is so conclusively proved

[1] *Physiologische Optik*, p. 553.

by Professor Kirschmann to be referable—the parallax of indirect vision—is a supplement (and for one-eyed persons a substitute) to the conditions proved by Wundt to be essential for the perception of lustre, whether binocular or monocular. Inasmuch as this work on metallic lustre has been extensively discussed in French and German publications, but not hitherto in English, there is given here the summary with which the author concludes his exhaustive investigation of the subject. The summary is translated directly and in full in order to preserve the quasi-mathematical character of its demonstration *per exclusionem*.

1. Metallic lustre is a characteristic phenomenon which everybody distinguishes from other light phenomena independently of any previous knowledge of the objects, illumination, etc. A definition of metallic lustre can therefore claim no more value than a definition of the sensation red. The designation of the phenomenon is quite irrelevant. "Metal" and "metallic lustre" have psychologically nothing to do with each other.

2. For our consciousness light impressions are distinguished only with regard to intensity, quality (colour and saturation) and space and time relations. The phenomenon of metallic lustre must accordingly be referable to these four factors or a part of them.

3. As regards intensity there are three elements: (*a*) intensity of the whole surface, (*b*) intensity-relations of the parts of the surface to one another or of the whole surface to other impressions, (*c*) changes of intensity. The possibilities which come under (*b*) and (*c*) belong also under the space and time relations and will be discussed in connection with them. Since metallic lustre is entirely independent of the strength of the illumination, it cannot depend on the absolute intensity of the whole surface.

4. Since there are completely colourless metals, and since further metallic-lustrous surfaces retain their characteristic property in coloured, and even in approximately monochro-

matic light, the participation of the colour-tone and saturation in the essential conditions of metallic lustre is excluded.

5. As regards the time-relations metallic lustre is independent of the duration of the total impression of the surface concerned; it is perceived in very short, so-called instantaneous illumination. Moreover a change in the properties of the total impression cannot be the cause of metallic lustre, since the latter is perceived in demonstrable constancy of the optical relations between the surface in question and the eye. The temporal relations of single parts of the surface fall also under space relations, and will, therefore, be discussed in the following paragraphs.

6. The space relations are either those of the whole surface or those of the parts of the surface to one another. The space relations of the whole surface are form, size, and position relations to other surfaces in the vision-field. Form and size are quite irrelevant for metallic lustre. Since, moreover, the environment of the metallic-lustrous surface is without influence on the characteristic of the phenomenon, the metallic lustre cannot depend on the space-relations of the whole surface. The only condition with regard to the space-relations of the total impression is that there must be a surface. A point in the vision-field, i.e., a light impression not perceived as a surface, no matter what its intensity or its changes of intensity, never has the property of lustre.

7. There remains now as the only possibility the conclusion that metallic lustre depends on spacial or spacial-temporal relations of the parts of the impression to one another. These relations can only have a meaning if the parts of the impression which come in question show differences of quality or intensity. But since, as mentioned above, metallic lustre occurs in objects which reflect completely colourless light, and since, further, monochromatic illumination does not destroy metallic lustre, the quality of the parts of the impression cannot be influential. Metallic lustre must, therefore, depend on spacial or spacial-temporal relations of parts of the total impression which differ in intensity.

8. These relations of the parts of the impression or of the retinal images to one another are either constant, therefore spacial only, or changing, therefore spacial-temporal. If constant space relations were the basis of the phenomenon of metallic lustre, then it must be possible to reproduce this phenomenon through a certain arrangement of different intensities in the surface. But this is not the case. There can accordingly only be inconstant relations concerned. These may be: (*a*) intensity-changes with fixed space relations, (*b*) intensity-changes with changing space relations. The first case can occur only if the parts of the metallic-lustrous surface are either self-luminous or illuminated independently of each other by changing light-sources of different intensities. This case is, however, entirely excluded. The question must, therefore, be concerning changes of intensity with changing space relations.

9. The occurrences, which, so far as concerns the retinal image, play their part in two-dimensional space, must, so far as the objects are concerned, either be likewise of a two-dimensional nature or demand for their occurrence the depth dimension. In the former case a change of position of the points of different intensity in the surface must be assumed. This change of position cannot be caused by a change of the spacial relation of the object-surface to the eye; for through such a change nothing would be effected which could not also be produced by movement of objects with dull and not homogeneous surfaces. Since, however, in the metallic-lustrous objects known to us we cannot speak of an objective change of position of single reflecting parts, there remains then only the possibility that the objective arrangement of the light upon which metallic lustre depends is three-dimensional.

10. Inconstant three-dimensional relations in visual space with constant space-relations of the parts of the object to one another can only be parallactic relations. Metallic lustre must accordingly have its cause in some parallactic relation between sight-organ and object.

11. There are three parallactic relations possible in three-dimensional visual space, (1) the binocular parallax, (2) the

movement parallax, (3) the parallax of indirect vision. The binocular parallax can have no influence upon the phenomenon, for the latter is quite as well perceived monocularly. It never seems to play even an auxiliary part. For in the binocular union of stereoscopic photographs, the surface lustre shows excellently, but there is no trace of metallic lustre. The parallactic phenomena depending on the change of place of the object or of the eye have no meaning for metallic lustre for it is perceived with the unmoved eye and with complete rest of the object.

12. It follows then as the only possibility that metallic lustre depends on the parallax of indirect vision.

13. The phenomena of the parallax of indirect vision are, in apparently homogeneous surfaces, as the metallic-lustrous bodies seem to possess them, possible in the following cases:

(*a*) If the surface is not actually even or of constant curvature, but is made up of many small surfaces inclined to one another, which reflect regularly and are so small that they cannot be perceived separately. Since every one of these small mirror surfaces reflects the rays coming from the strongest light-source only in one direction, every change, even the slightest, of the position of the object or of the eye and every smallest fluctuation of the accommodation or fixation must produce a change in the position and brightness relations of the single light points. These changes or parallactic displacements are indeed too small to be directly spacially perceived. But they are great enough, on the ground of the peculiar use of the parallax of indirect vision for depth perception, to give rise to a characteristic phenomenon which is not to be mistaken for any other.

(*b*) If the metallic-lustrous body consists of many small parts (crystals) which are separated by empty interstices (or interstices filled with an optically thin material) and which regularly transmit a large proportion of the light, and have mirroring (i.e., regularly reflecting) surfaces. The light re-

(1) *Vide* article by the same author on *Die Parallaxe des indirecten Sehens und spaltförmigen Pupillen der Katze.* (Philos. Studien, ix, 447 etc.)

flected in a given direction consists then of several components, which, because of the different reflection-sources, have a more or less great path-difference. The components of one and the same ray, therefore, act as rays from different distances. Every change in the dioptric condition of the eye (change of the accommodation, displacement of the diaphragms in the rotation of the eye around its centre), even if it is extremely small and takes place quite unconsciously, must, therefore, entail the above-mentioned changes in the configuration of the bright and dark points of the retinal image, which are characteristic for the parallax of indirect vision.

Of these two possibilities the latter seems to be the more probable, inasmuch as it is confirmed by the results of physical investigations.

14. It must be possible to produce the phenomenon of metallic lustre artificially by wholly non-metallic means, so far as the conditions can be reproduced for the occurrence of the parallax of indirect vision in such a way that the parallactic displacements cannot be directly recognized as changes of position and distance. [This conclusion is experimentally completely confirmed by the preparations made by Professor Kirschmann and described in the article from which the above summary is translated.]

2. *Experiments on Intensity as a Condition of Lustre.* We return now to our subject proper, viz., the relation of intensity to the perception of stereoscopic lustre. The characteristic of lustre, as we have seen, is incomplete mirroring, or the combination of regular and diffuse reflection. A lustrous surface reflects the light which falls upon it partly diffusely, i.e., indifferently in all directions, and partly regularly, i.e., with a constant relation of the angles of incidence and of reflection. From a certain direction or directions, a lustrous surface, on account of this regular reflection, appears brighter than from all others. Therefore, in binocular vision a given point in a lustrous surface has never the same intensity for the two eyes; and the nearer the approach to complete mirroring the greater will be the difference. Now by making use of the stereoscope

we can construct the objects to be presented to the two eyes separately so as to produce by independent illumination of them those differences of brightness which in ordinary binocular vision are due to the spacial relations of the object to the respective eyes. Having the conditions thus under control we can vary the relation of the intensities at our will, and by this means can determine within what limits of brightness contrast between the retinal images the phenomenon of lustre occurs.

The lustre thus produced is sometimes called an "illusion" of shine or polish.[1] The difference, however, must be pointed out between this case and those referred to by Kirschmann, as cited above, where the appearance of lustre is produced in a painting by pigments of contrasting brightness or on a dull surface by appropriate independent illumination of adjacent parts. In the latter cases the same optical conditions do not exist as in the perception of genuine lustre, as may be seen by moving the head or closing the eyes alternately, when the brighter part of the surface does not change its relative position, as would be the case if the surface were lustrous. Such a case may be properly termed an illusion, because a characteristic that is taken for a sensational element is in reality supplied by memory or imagination. In the case of images of different intensity binocularly combined by the help of the stereoscope, however, the optical conditions are precisely those which exist in the ordinary binocular perception of lustre, although produced by different objective arrangements, and there is, therefore, psychologically no reason for calling it an illusion; it is real lustre.

For the purpose of determining the limits of intensity contrast for the production of stereoscopic lustre, some experiments were made with an apparatus the same in principle as that employed for the experiments in depth perception, referred to in a preceding section. As, however, the apparatus was re-constructed, introducing some improvements, a full description is here given, and a stereoscopic picture of it is

[1] Sanford, *Experimental Psychology*, p. 172.

shown in Fig. 4. To the front of a table 68 cm. square, at a height of 35 cm. above it, are fixed two stereoscopes, the inner lens of each of which may be covered by a small shutter, which has a spring to keep it open when not in use. Behind the stereoscopes is an episkotister disc turned by an electric motor; this disc is constructed so as to vary the light transmitted from 0° to 320°. The stereoscopes are arranged before the episkotister in such a way that one eye looks through it, while the other is unobscured. Close behind the disc is a thin wooden screen of the width of the table and 60 cm. in height, painted a dead black. Through this screen are cut two openings on each side 50 mm. square, opposite the lenses of the stereoscopes. Behind this again is a second black wooden screen, attached to the table in such a way as to be easily moved backward or forward. On this screen the objects are fastened. Each set of objects was lighted by an electric lamp placed between the screens, and suspended from the front one. The motor which turned the disc was also placed between the screens. The adjusting of the disc was facilitated by the use of an incandescent lamp attached by a bracket to the front of the apparatus, which was turned off during the observations, and when in use screened by a shade from the eyes of the observer. The experiments were conducted in a dark room, and the apparatus covered with a black cloth, so that the eyes might be shaded as completely as possible from all light except that reflected from the objects to be observed. The objects used were of two kinds. Those shown in Fig. 5 were drawings on black and white paper respectively, having a back-ground of grey cardboard to which the drawings were fixed. The two drawings, when combined by means of the stereoscope, presented the appearance of a truncated hexagonal pyramid, with its apex projecting towards the observer. A modification of the drawings as shown in the cut was made by drawing the lines, both on the black and white, with gold bronze, the contrast between the black and white lines being so great as to cause strife of contours. The other objects used were also outline drawings,

which were etched upon small squares of thin plateglass, an placed over the openings in the front screen of the apparatu squares of white cardboard and black velvet respectivel being fixed behind them upon the screen at the back of th apparatus. These etchings are illustrated in Figs. 6 and One pair of them forms, when combined stereoscopically, truncated pyramid which projects toward the observer. Th other pair forms a transparent octohedronal crystal. In th experiments the drawings were so placed at first that the on on the black ground was seen directly, that on the whit through the episkotister disc. By diminishing the amoun of light admitted through the episkotister the light reflecte from the white surface was approximated to that reflecte from the black, till at a certain point the intensities woul be equal, and beyond that again the white surface woul become the darker. Beginning then on the left hand wit the left eye unobscured regarding the drawing upon the blac surface, and the right eye looking through the episkotister a the drawing upon the white surface, the disc was set so as t admit only a single degree of light. The observer then looke through the stereoscope and reported the effect both as t lustre and as to the stereoscopic combination of the object Then changing over to the right stereoscope the observatio was repeated, but this time with the obscured white objec before the left eye and the unobscured black before the righ eye. The disc was then adjusted to admit a little more ligh and the observations repeated, and so on until the point ha been passed beyond which no difference was observabl whether the one eye was obscured by the disc or received th full light. Then beginning at a point beyond this upper limi the light was gradually decreased to the least amount that th disc could be adjusted to admit. A second series of trial was then made with the objects transposed, so that the whit was seen directly and the black obscured by the episkotiste the effect of which was of course to make the difference be tween the intensities of the two impressions greater than tha between the black and white used in equal illumination, an

at each increase of the amount of light admitted through the disc to diminish instead of increasing the difference of intensity. The illumination used throughout was, with the drawings upon paper, that of a 32 c.p. electric lamp on each side; with the glasses 16 c.p. lamps were used. The results are given in Tables X-XII. The judgments were found to be somewhat difficult, and the results of other than trained observers were not, therefore, of much value. The number of observers whose results are given is small, but all had the advantage of much practice.

TABLE X. OBJECT, HEXAGONAL PYRAMID. AVERAGE OF FOUR OBSERVERS.

Opening of Disc		Ratio of White to Black	Lustre	Stereoscopic Effect
White Obscured	Black Obscured			
2½°	....	.31	None.	Partial.
12¼°	....	1.53	Slight	Partial.
16°	....	2.00	Slight.	Complete.
50°	....	62.50	Good.	Complete.
....	55°	360.00	Good.	Complete.
....	43¾°	375.69	Good.	Partial.
....	16½°	996.76	Slight.	Partial.
....	9½°	1705.26	None.	Partial.

TABLE XI. OBJECT, RECTANGULAR PYRAMID. AVERAGED RESULTS OF THREE OBSERVERS.

Opening of Disc		Ratio of White to Black	Lustre	Stereoscopic Effect
White Obscured	Black Obscured			
9°	....	2.89	None.	Partial.
10°	....	3.21	Slight.	Partial.
18°	....	5.78	Slight	Complete
42°	....	13.50	Good.	Complete.
....	110°	378.70	Good.	Complete.
....	71°	586.72	Imperfect	Complete
....	23°	1811.18	Slight.	Partial.
....	*20°	2082.85	None.	Partial.

* Average of two observers only.

TABLE XII. OBJECT: CRITICAL. AVERAGED RESULTS OF THREE OBSERVERS

Opening of Disc		Ratio of White to Black	Lustre	Stereoscopic Effect
White Obscured	Black Obscured			
5°	....	1.50	None	Partial
8°	....	2.57	Slight	Partial.
14°	....	4.52	Imperfect	Complete.
30°	....	9.54	Good	Complete.
....	55°	771.72	Good	Complete.
....	45°	520.00	Good	Complete.
....	25°	1666.23	Slight	Partial
....	21°	1983.66	Slight.	None.

The first column of the tables gives the openings of the disc (in degrees) when the drawings upon white were obscured by the episkotister. The second column gives the openings when the black is obscured by the disc. The third column shows the relation of the intensities of the white seen to those of the black. This is obtained by measuring photometrically the relative intensities of the black paper, the black velvet, and the white paper used, and from those measurements and the epistokister openings calculating the intensity in each case. The numbers given represent the intensity at each point where a change occurs, either as to the lustre or the stereoscopic combination of the objects. Beyond the limits of the numbers given, in either direction, there was neither lustre nor stereoscopic effect.

A curious phenomenon noticed by some observers in the course of these experiments was a sort of depth contrast. When the shutter on the front of the stereoscope was closed for the purpose of comparing the monocular with the binocular effect, the stereoscopic depth would first disappear, and then sometimes there would appear a distance effect the opposite of that seen with the shutter open; e.g., when stereoscopically there appeared a pyramid with the apex toward the observer, on the closing of the shutter there would be first a flat surface with lines upon it, and then in a moment came a hollow pyramidal box with the base toward the observer.

SUMMARY OF RESULTS.

1. For the production of any, even the slightest, degree of stereoscopic lustre, one retinal impression must be, on an average, from one and a half to three times as bright as the other, according to the objects observed.

2. Greater constancy is apparent regarding the upper limit of contrast, beyond which no lustre appears, which is, approximately, when one image is about 1900 times as bright as the other.

3. The figures regarding the limits for perfect lustre are the least regular, the lower limit ranging from a ratio of white to black of 9.64 to one of 62.50, and the ratio at the upper limit varying from 375.69 to 920.00. The reason for the greater variation here is no doubt the complexity of the judgments required. It is difficult to determine what is to be set down as perfect or imperfect, and probably no two observers would give the same decision upon that point, nor even the same observer at different times.

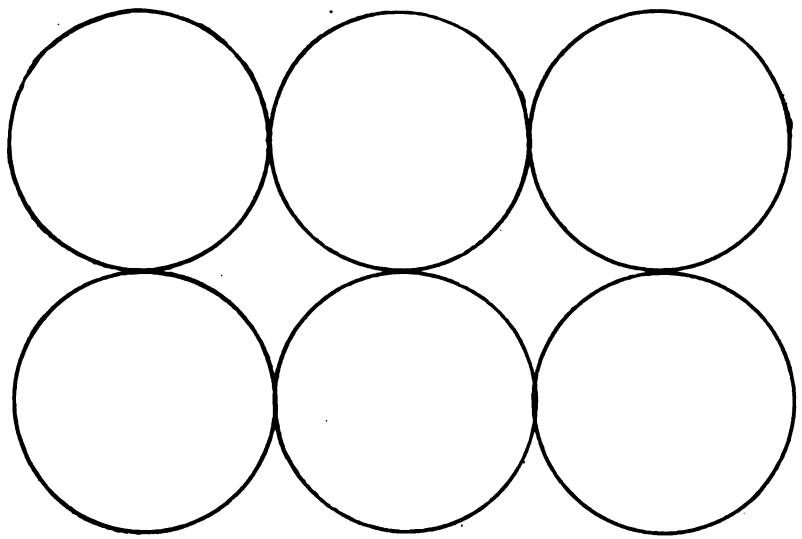


FIG. 1

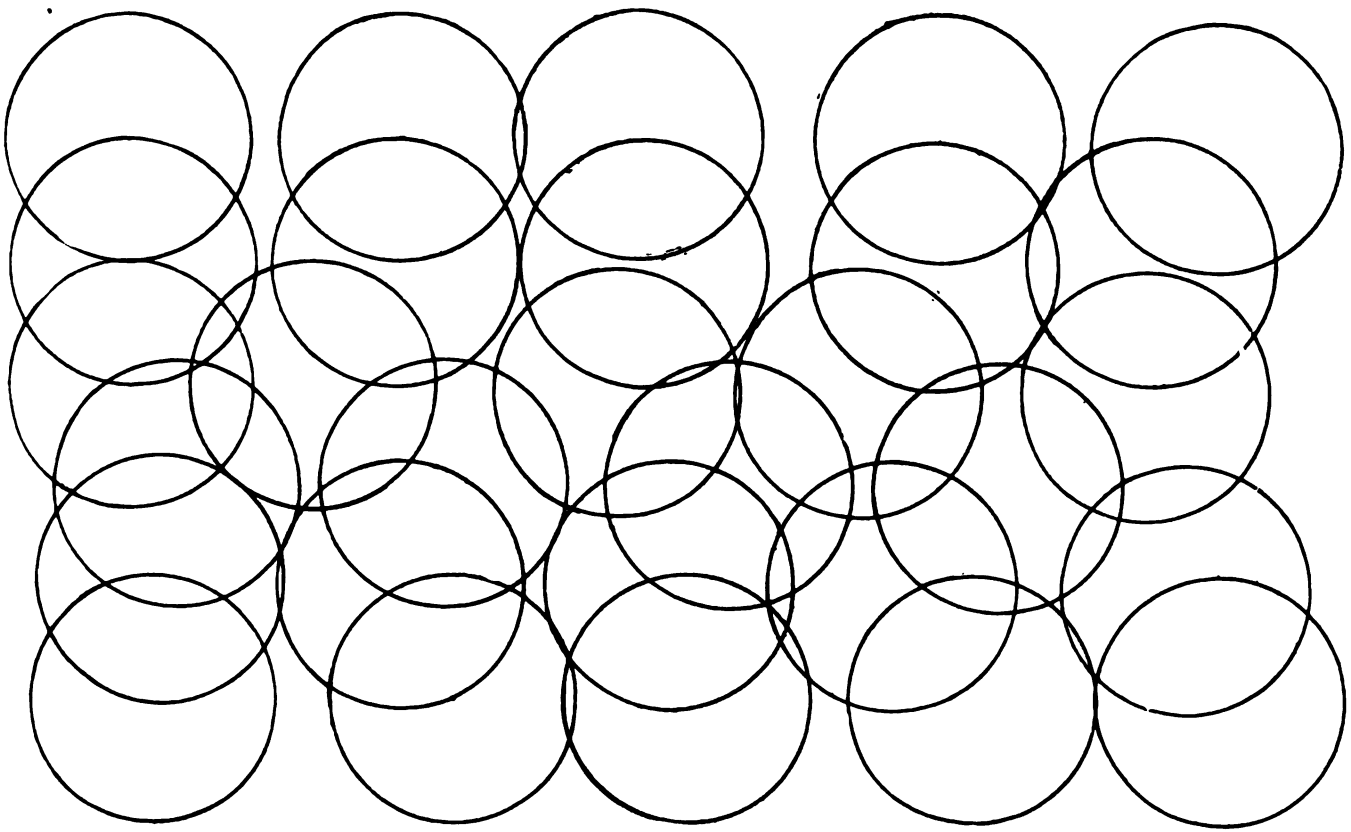


FIG. 2

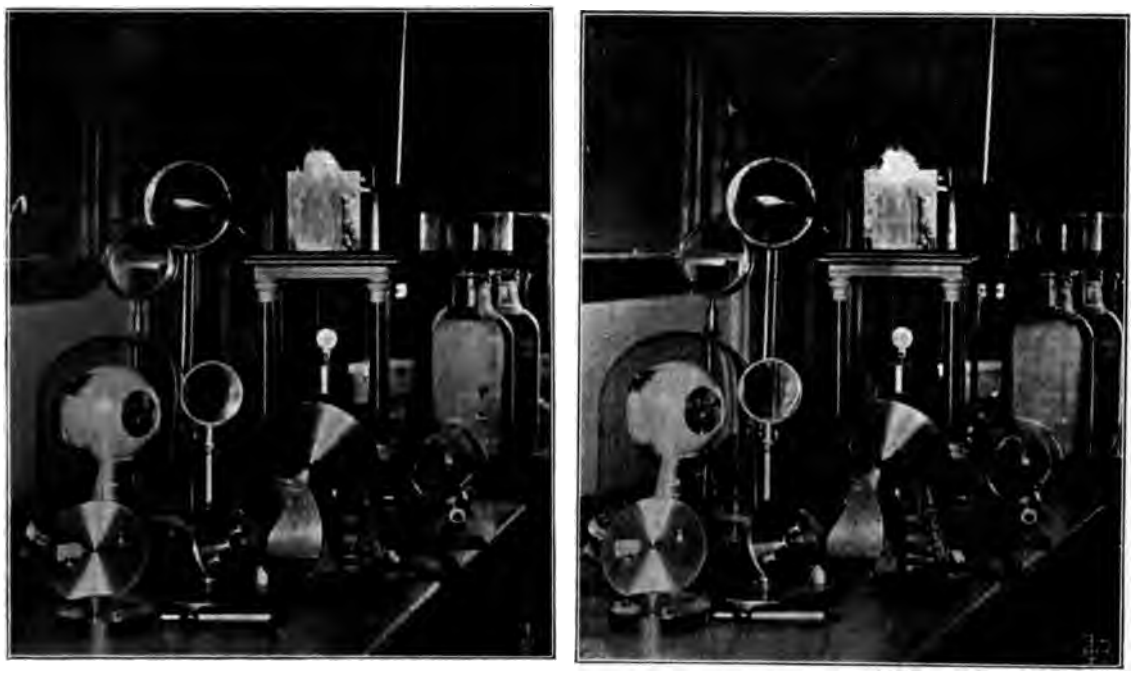


FIG. 3

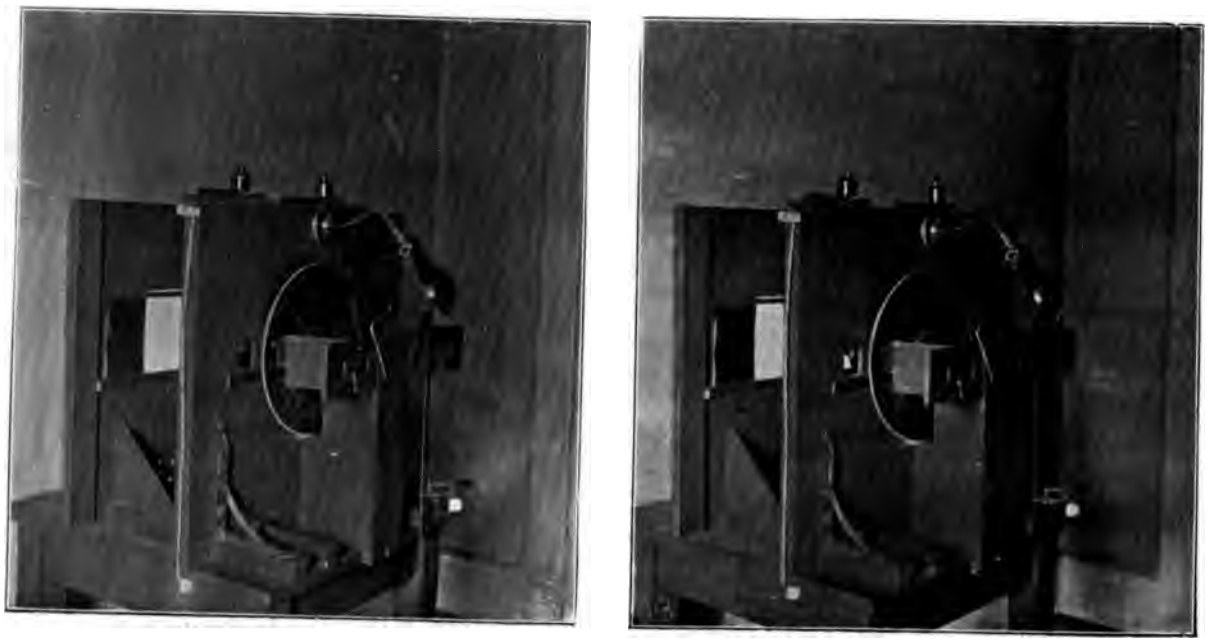


FIG. 4

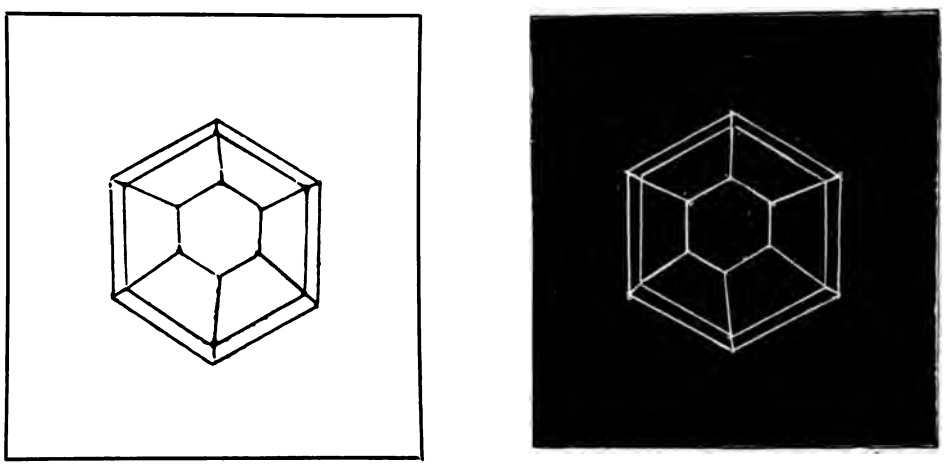


FIG. 5

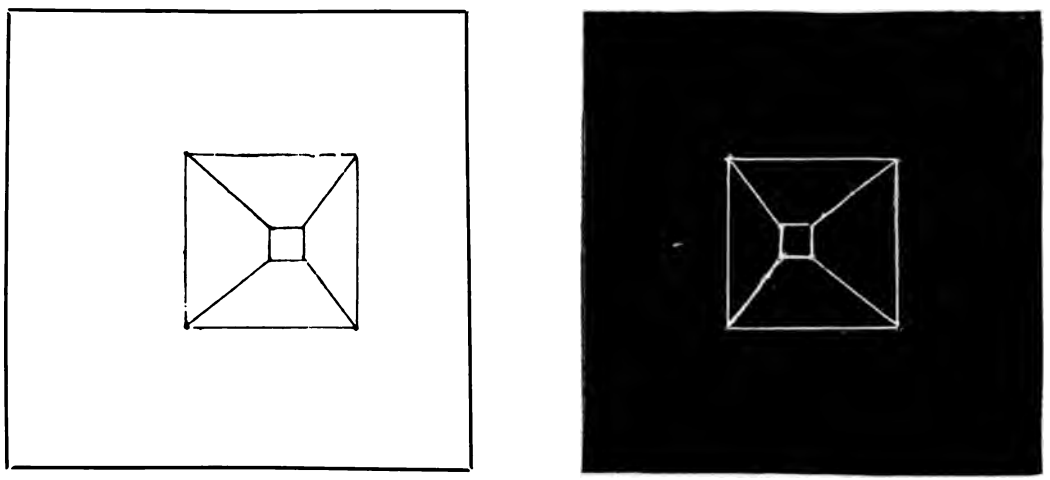


FIG. 6

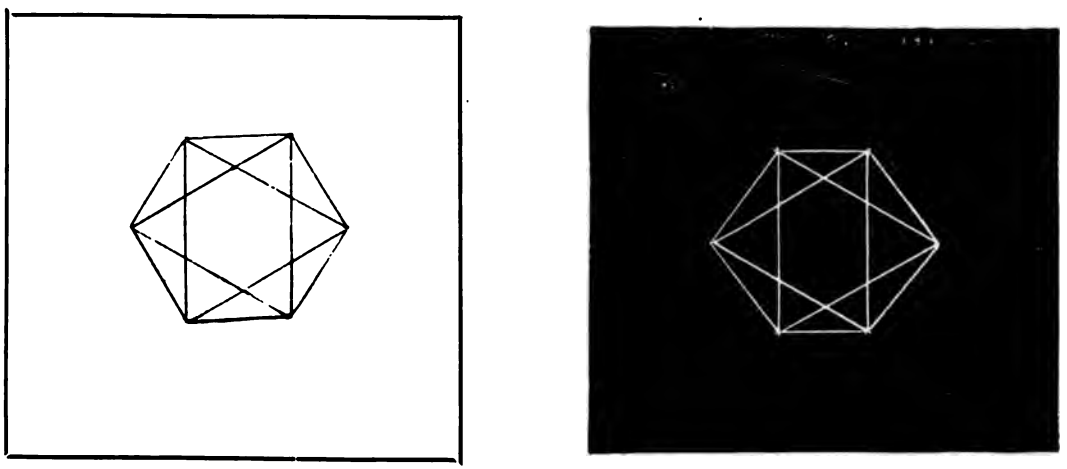


FIG. 7

COLOUR AESTHETICS

COMBINATIONS OF COLOURS WITH TINTS AND WITH SHADES

BY

F. LOUIS BARBER, B.A.

COMBINATIONS OF COLOURS WITH TINTS AND WITH SHADES

The experiments reported in the following paper are a continuation and a natural supplement to those of Miss Baker and Miss Chown published in Volumes I and II. The former, Dr. Baker, has furnished most valuable results with regard to the colour harmony in binary combinations of colours of full saturation; and Miss Chown's investigation has given conclusive results with regard to the combinations of colourless light with the colours (full saturation, shades and tints). There remains then to investigate the harmony between the colours, on the one side, and the tints and shades on the other, and that between the tints and shades among themselves (T_2 with T_2, S_2 with S_2, S_2 with T_2, and T_2 with S_2). The first half of this task, i.e., the harmony between the colours and the tints and shades, is our present subject.

The experiments under discussion here were conducted in the Psychological Laboratory of the University of Toronto. The room was lighted uniformly by skylight, and the judgments were made in the afternoons at about the same time, in order to secure equal light intensity, so that as far as possible the phenomenon of Purkinje might not affect the results. Other conditions of distance from, and angle with the table, etc., were kept as uniform as possible. Upon a table with a sloping top covered with black velvet the 24 combinations were arranged in two rows, 1 to 12 and 24 to 13, no. 24 being under no. 1. Each combination consisted of two coloured cards, 83 x 33.5 mm., one colour (or its shade or tint as the case might be) being the same (constant) in all of the 24 pairs displayed at one time, the other colour (or shade or tint), called the variable, being that corresponding to the number placed above it. These variables always formed a colour-circle in uninterrupted spectral order; the combinations were 100 mm. apart. Thus it is seen that according to this method a constant would be combined with each of the 24 variables at each trial, and in a series of 24 each of the 24 constants would be combined with each of the 24 variables.

There were ten observers, varying in age and of either sex. They were asked not to consult one another regarding their results, and also to make their judgments from the immediate impression of the combinations as free as possible from distracting associations of other shapes, sizes and uses that imagination might present. Each observer completed the whole four series and recorded the numbers of the combinations found agreeable. In a second and third column were recorded those found most agreeable and unpleasant respectively.

In all experiments the constant was placed at the left of the variable, and as each constant appeared also as a variable at the right of its corresponding constant (previously a variable) each combination appears in both ways. Hence, as we combine our results the space-error is eliminated. To eliminate the time-error the order in which the constants were chosen was not that of the spectrum or any other, but they were selected at irregular intervals, so that the choices would not result from a similarity of the series with the one preceding.

Cohn used 10 colours in his experiments, giving $\frac{10 \times 9}{2} = 45$ combinations. Miss Baker and also Miss MacDougall used 24 colours, giving $\frac{24 \times 23}{2} = 276$ different pairs. Miss Chown used 24 colours with 5 greys and black and white, giving $24 \times 7 = 168$ combinations. In the present experiments the multiplier is not diminished by 1, as in Miss Baker's, on account of the colour with itself giving no binary combination. The colour with its own shade or tint gives a true combination; hence we have $24 \times 24 = 576$ in each of four series, or 2304 different combinations in all. As the number of observers is 10, and as each combination appears twice, therefore the number of judged combinations is $2304 \times 10 \times 24 = 46080$.

Tables I to IV give a condensed statement of the results. In the horizontal line of figures at the top of the table, and in the vertical line at the left, are the ordinals of the tints or shades and of the colours in full saturation, respectively. All the other numbers are cardinals, and each indicates how

many times the particular colours and tints (or shades), indicated by the corresponding ordinals at the left and at the top, have been chosen. The columns at the bottom and at the right side of the tables give the totals for the tints (or shades) and for the colours respectively.

Tables I and II refer to combinations of colours and tints; Tables III and IV refer to combinations of colours and shades. Tables I and III report the "pleasant" and Tables II and IV the "most pleasant" combinations. "Unpleasant" judgments are not reported here although they are on record.

Since the tables are not easily surveyed it will be convenient to employ curves for the further discussion of the results. For this purpose a curve has been drawn for each colour, shade, and tint, analogous to those published by Miss Baker for the individual colours. Of these ninety-six diagrams we can give here only a few samples. Fig. I, for instance, deals with the combinations of colour 15 with the tints, while Fig. II refers to the combinations of tint 15 with all the colours. It may be mentioned that for other colours the difference between the curve for the colour in full saturation and that one for the tint differs sometimes more widely than in the present example. In a similar way Figs. III and IV give the curves for the combinations between colour 15 and the shades, and shade 15 and the colours. The upper curve always refers to the "pleasant," and the lower to the "most pleasant" combinations. In order to see what rôle complementarism plays in these combinations we have marked in these curves (as also in the later ones) the place of the complementary colours by a cross (+).

In Figure I, and in the corresponding diagrams for the other colours, not published here, the ordinates of the curves are an indication of the frequency with which the fully saturated colour has been chosen in combination with the tints. In these diagrams we see, just as in Miss Baker's, the unmistakable peaks in the curves for red, indicating a preference for a certain region of the colour circle, turn, in the orange and yellow, into a more indifferent plateau-like series of smaller

TABLE I.

TINTS AND COLOURS.

PLEASANT COMBINATIONS.

No. of Colours	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	Tints
1	5	7	6	6	7	8	9	10	10	9	13	10	10	9	6	3	5	4	2	2	4	1	3	3	152
2	3	4	3	6	5	7	7	7	6	7	9	9	9	6	4	3	6	3	3	2	2	0	2	2	115
3	1	6	3	5	6	6	4	5	8	8	8	8	7	5	4	5	4	3	2	1	1	2	3	4	109
4	3	6	7	7	6	5	7	5	7	7	8	6	4	6	5	4	4	4	1	1	0	3	6	2	114
5	1	2	2	4	6	9	8	4	5	4	5	4	5	6	8	6	4	4	1	2	3	2	4	2	101
6	3	4	3	7	9	10	9	6	3	5	8	5	6	10	7	7	6	7	4	5	5	7	5	5	146
7	4	6	6	6	8	9	12	8	7	5	9	4	6	10	8	8	8	10	8	5	10	9	7	7	180
8	4	4	5	8	8	9	10	7	5	9	12	8	11	11	11	9	9	7	6	7	9	10	7	7	193
9	4	3	4	6	4	5	8	8	5	7	9	8	9	10	8	7	5	11	10	7	6	6	4	5	159
10	8	5	6	8	7	5	7	5	10	10	9	8	8	7	5	3	3	9	7	8	9	6	5	7	165
11	9	6	5	8	8	7	7	9	14	11	9	7	7	4	5	6	5	5	7	6	6	5	6	8	170
12	5	7	6	8	9	7	10	10	10	10	12	11	10	7	3	4	6	6	5	8	7	6	5	8	180
13	7	7	5	10	6	7	8	9	13	12	13	12	11	12	8	5	3	7	5	7	7	7	7	8	196
14	4	2	3	3	3	7	6	7	6	10	11	12	13	14	13	11	3	8	6	9	5	6	8	6	176
15	6	6	4	8	7	7	6	6	5	4	7	8	6	13	12	9	6	8	5	8	5	7	6	7	166
16	3	2	1	3	5	6	7	6	7	5	7	4	4	13	10	11	9	5	5	3	2	1	4	2	125
17	3	2	2	5	5	3	5	6	7	5	7	6	3	6	3	8	9	6	4	7	3	1	2	2	110
18	4	1	2	4	3	6	8	8	7	7	7	6	5	7	6	6	7	6	6	8	3	2	1	1	121
19	5	2	1	3	7	6	5	4	5	8	7	4	4	8	6	5	14	11	13	11	6	4	1	1	141
20	4	1	3	5	7	6	4	5	3	8	9	7	4	7	6	3	7	11	15	12	11	8	2	1	149
21	5	3	3	7	7	7	9	8	6	5	6	5	3	6	6	5	7	6	9	14	13	7	5	2	154
22	8	6	5	7	8	7	6	6	7	5	7	9	6	7	4	6	3	0	1	1	4	10	6	9	138
23	8	6	5	6	7	9	11	10	7	6	8	6	6	7	4	4	3	4	1	1	0	5	12	8	144
24	7	7	5	5	4	6	9	9	8	5	8	6	4	7	5	6	5	2	1	3	1	3	6	6	128
Total	114	105	95	145	152	164	182	168	171	172	208	173	161	198	157	144	141	147	127	138	122	118	117	113	3532

TABLE II.

TINTS AND COLOURS.

MOST PLEASANT COMBINATIONS.

No. of Colours	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	Tints
1	2	2	3	2	1	0	2	0	0	2	3	5	3	1	2	2	1	1	1	1	2	1	1	1	39
2	1	2	0	3	2	0	1	1	0	2	3	3	2	1	1	2	3	1	1	1	1	0	1	2	34
3	0	2	1	3	2	1	2	2	1	2	4	4	2	1	1	1	1	0	0	0	0	0	1	3	34
4	0	1	3	4	1	0	2	2	1	2	1	3	1	2	1	2	1	0	0	0	0	0	3	2	32
5	0	1	2	2	2	4	1	2	0	2	2	3	1	2	2	2	1	0	1	1	2	2	2	1	38
6	1	2	2	2	2	4	4	0	0	0	3	0	2	2	2	3	1	0	1	0	3	1	1	2	38
7	1	1	3	4	2	4	6	3	2	0	3	1	2	4	3	1	1	1	0	1	4	3	3	2	55
8	0	1	1	3	2	4	3	1	1	3	3	3	1	6	4	3	2	1	1	1	2	4	1	1	52
9	0	0	0	2	2	3	2	4	1	1	2	2	2	4	4	3	0	1	1	2	3	1	2	4	46
10	3	0	1	3	4	3	2	2	3	3	2	2	4	2	1	0	0	4	2	3	5	2	3	3	57
11	4	2	1	3	2	3	0	1	6	3	2	2	2	1	2	3	1	2	2	3	4	1	2	3	55
12	1	2	2	3	3	3	2	3	4	3	5	6	3	1	1	1	1	3	2	4	2	0	4	4	63
13	2	0	0	0	1	1	2	2	0	2	5	7	7	1	4	1	1	1	1	3	3	1	2	1	48
14	2	0	1	1	1	1	1	2	1	2	5	6	8	7	7	3	1	1	2	4	2	3	1	1	63
15	1	2	0	1	1	3	2	0	1	2	1	0	2	5	6	5	1	2	1	0	1	2	4	4	47
16	1	1	0	1	0	1	1	2	1	1	4	0	1	3	1	7	3	1	1	1	0	0	0	0	31
17	1	0	0	2	0	1	1	1	1	2	1	0	1	1	0	2	6	4	0	1	1	0	1	1	28
18	0	0	0	2	2	1	2	2	2	2	3	3	1	1	2	3	3	3	3	1	0	1	0	1	38
19	0	0	0	0	1	1	1	1	1	2	1	0	1	1	1	1	5	5	6	4	1	1	1	1	36
20	0	0	1	2	3	2	1	0	1	0	0	1	1	0	0	0	3	5	7	8	8	4	0	1	48
21	1	0	0	1	1	0	2	1	1	1	0	1	1	1	0	1	2	3	3	9	10	5	1	0	45
22	3	1	1	1	1	0	1	2	1	1	2	3	1	2	1	1	2	0	1	0	0	4	5	8	42
23	3	3	1	1	3	2	3	1	2	2	2	4	1	2	0	0	0	0	0	0	0	1	5	4	40
24	1	0	0	3	2	2	2	3	3	4	2	1	0	4	1	1	3	0	0	0	0	1	2	4	39
Total	28	23	23	49	41	46	46	38	34	44	59	60	50	55	47	48	43	39	37	48	54	38	46	54	1048

TABLE III.

SHADES AND COLOURS.

PLEASANT COMBINATIONS.

No. of Colours	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	Shades
1	4	5	6	7	7	9	10	7	11	9	12	8	9	12	9	8	7	8	7	7	6	4	3	4	179
2	6	7	5	8	5	9	9	10	10	7	9	7	7	7	5	4	8	5	4	4	7	6	5	5	159
3	9	6	7	8	10	12	11	12	8	8	10	7	7	4	5	4	5	5	5	3	6	5	4	5	166
4	6	6	5	7	9	11	9	10	8	8	6	7	9	6	4	3	4	2	6	4	8	5	4	7	154
5	8	6	6	9	12	15	8	12	10	8	7	4	8	6	4	6	6	4	7	5	8	6	7	5	177
6	12	14	9	10	14	13	14	12	9	11	11	11	8	6	5	7	8	8	10	8	8	8	13	9	238
7	10	13	10	13	14	15	13	11	11	13	10	9	6	5	6	8	8	6	8	6	10	12	10	8	235
8	13	11	8	8	8	9	14	9	11	12	6	9	11	8	9	5	9	8	6	5	6	5	7	8	205
9	8	5	4	5	4	10	7	10	6	7	6	5	7	6	6	5	7	6	6	7	7	4	4	5	147
10	5	8	9	8	6	8	8	9	9	7	7	4	6	5	6	4	7	5	6	5	5	5	6	6	154
11	11	11	8	10	8	10	9	9	8	10	12	8	10	9	5	6	6	6	4	8	6	8	7	10	199
12	8	7	6	9	6	9	12	10	7	6	7	6	9	4	7	6	7	7	6	7	6	10	14	11	187
13	9	9	7	7	7	10	10	7	8	7	9	5	7	5	6	10	7	8	4	5	3	5	11	9	175
14	10	6	6	7	6	9	9	7	7	11	7	8	8	7	5	6	7	8	5	8	6	4	7	9	173
15	7	3	6	10	7	8	8	7	7	6	3	6	4	4	2	4	4	6	3	4	4	4	7	6	130
16	8	3	8	8	3	7	9	8	8	6	6	6	7	8	4	3	2	4	1	1	3	1	3	3	120
17	5	5	8	6	8	7	7	8	7	3	5	4	4	5	3	4	4	5	3	0	2	2	3	2	110
18	5	2	4	6	5	5	4	7	7	1	7	6	5	6	4	2	6	6	6	2	3	3	3	3	108
19	7	2	5	5	3	5	5	5	7	4	4	7	7	4	4	3	3	6	5	2	2	2	2	4	103
20	4	4	4	5	6	10	9	2	6	5	6	6	12	7	6	4	3	4	9	4	3	2	3	5	120
21	4	5	5	6	5	6	6	5	2	4	5	5	7	7	4	3	3	5	7	6	7	3	3	4	117
22	4	6	5	4	8	10	12	11	10	10	9	11	9	9	10	6	4	4	7	6	7	8	9	6	185
23	4	6	3	5	5	7	10	14	10	7	9	8	6	9	9	7	7	5	7	5	6	4	7	5	165
24	4	7	6	8	10	10	11	14	7	6	8	10	12	11	9	7	6	9	7	7	5	5	5	6	190
Total	171	157	150	179	176	224	224	216	194	176	181	167	185	160	137	125	138	140	130	119	134	121	147	145	3005

TABLE IV.

SHADES AND COLOURS.

MOST PLEASANT COMBINATIONS.

No. of Colours	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	Shades
1	2	3	0	5	2	4	2	2	3	3	4	1	4	6	3	1	2	3	2	2	1	1	2	3	61
2	2	3	1	3	1	1	2	0	3	3	5	1	2	2	1	0	0	1	1	1	2	2	2	3	42
3	3	2	2	3	4	4	4	3	1	2	2	3	3	2	0	1	0	1	1	0	2	1	0	0	44
4	4	2	1	2	2	3	4	2	1	1	2	3	4	2	3	1	1	0	0	0	0	0	0	2	40
5	4	2	1	4	3	2	3	2	1	4	1	1	1	1	2	2	1	0	0	0	0	2	1	1	39
6	4	4	4	6	3	4	5	4	2	3	3	2	1	0	1	3	2	3	1	0	0	2	2	1	60
7	2	5	6	3	3	6	9	4	3	3	3	0	1	0	1	3	1	0	2	0	3	4	3	2	67
8	3	3	2	1	2	3	3	4	3	2	2	2	1	3	2	4	2	3	1	2	4	1	3	3	59
9	1	1	0	0	0	2	2	3	0	2	1	1	4	2	2	3	3	5	1	2	2	1	2	3	43
10	2	1	3	5	1	2	5	4	6	4	5	2	2	1	1	0	3	2	1	3	2	2	2	2	61
11	8	5	4	3	2	1	3	2	4	2	5	5	3	0	1	1	2	1	3	3	1	5	4	6	74
12	4	6	2	2	1	0	4	2	2	2	3	2	3	1	3	3	1	2	1	1	2	2	8	4	61
13	0	5	3	1	2	3	3	1	0	2	3	3	2	1	4	5	2	0	0	0	0	2	1	2	45
14	5	3	1	5	4	4	3	2	2	5	4	3	4	5	3	2	1	5	3	3	2	2	6	4	81
15	1	1	1	3	1	2	5	2	2	2	2	4	1	2	1	1	0	0	0	1	2	0	2	1	37
16	0	0	1	1	1	1	5	3	3	4	2	2	1	4	2	1	1	0	0	0	1	0	1	1	35
17	1	1	2	0	2	2	5	4	4	2	0	2	0	2	1	1	1	3	0	0	0	0	0	1	34
18	1	0	0	1	2	1	2	5	4	1	1	0	2	2	0	1	2	0	2	0	0	0	0	1	28
19	1	0	0	1	1	0	2	1	3	0	1	2	3	1	0	1	1	2	2	2	1	1	1	0	27
20	1	1	1	1	1	3	3	0	1	1	0	1	3	3	0	0	2	2	2	3	1	1	0	0	31
21	1	0	0	1	1	2	0	1	0	1	1	1	2	1	1	0	1	2	1	2	4	1	1	2	27
22	2	1	0	1	3	5	3	4	5	1	3	4	4	4	4	0	1	2	1	1	2	3	2	4	60
23	3	0	2	1	0	5	4	5	5	3	3	4	2	5	3	2	1	2	3	1	2	2	1	3	62
24	2	0	0	2	4	2	3	5	3	2	1	2	2	6	1	1	1	3	3	2	2	1	2	3	53
Total	57	49	37	55	46	62	84	65	61	55	57	51	55	56	40	37	32	42	31	29	36	36	46	52	1171

TABLE V.

TINTS AND COLOURS.

PLEASANT COMBINATIONS.

A.

Colours	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	Tints
Red.....	9	17	12	17	18	21	20	22	24	24	30	27	26	20	14	11	15	10	7	5	7	3	8	9	
Orange....	7	12	12	18	21	24	24	15	15	16	21	15	15	22	20	17	14	15	6	8	8	12	15	7	
Yellow....	12	13	15	20	20	23	30	23	17	21	30	20	26	31	27	24	22	28	24	19	25	25	18	19	
Yel.-Green	22	18	17	24	24	19	24	24	34	31	30	26	25	18	13	13	14	20	19	22	22	17	16	23	
Blue Green	17	15	12	21	16	21	20	22	24	26	31	32	30	39	33	25	12	23	16	24	17	20	21	21	
Blue.....	10	5	5	12	13	15	20	20	21	17	21	16	12	26	19	25	25	17	15	18	8	4	7	5	
Violet.....	14	6	7	15	21	19	18	17	14	21	22	16	11	21	18	13	28	28	37	37	30	19	8	4	
Purple.....	23	19	15	18	19	22	26	25	22	16	23	21	16	21	13	16	11	6	3	5	5	18	24	23	

B.

Tints	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	Colours
Red.....	18	10	10	16	5	10	16	13	11	19	20	18	19	9	16	6	7	7	8	8	11	19	19	19	
Orange....	21	18	17	18	19	26	23	25	15	20	23	24	23	13	22	14	13	13	16	18	21	22	22	15	
Yellow....	29	20	17	19	17	18	27	22	21	22	30	30	30	19	17	20	18	23	14	12	23	19	28	26	
Yel..Green	32	25	24	21	13	18	18	29	24	27	27	33	37	33	19	16	18	20	19	24	16	21	20	19	
Blue-Green	25	19	16	15	19	23	24	33	27	20	16	20	31	40	31	27	12	18	18	17	15	17	17	16	
Blue.....	12	12	12	12	14	20	26	25	23	15	16	16	15	22	28	25	23	19	30	21	18	9	11	13	
Violet..	8	7	4	2	6	14	23	22	23	24	19	20	19	20	18	10	14	17	30	38	36	6	2	5	
Purple.....	7	4	9	11	8	17	23	24	15	18	19	19	22	20	20	7	5	4	6	11	14	25	25	15	

TABLE VI.

TINTS AND COLOURS.

MOST PLEASANT COMBINATIONS.

A.

Colours	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	Tints
Red.....	3	6	4	8	5	1	5	3	1	6	10	12	7	3	4	5	5	2	2	2	3	1	3	6	
Orange....	1	4	7	8	5	8	7	4	1	4	6	6	4	6	5	7	3	0	2	1	5	3	6	5	
Yellow....	1	2	4	9	6	11	11	8	4	4	8	6	5	14	11	7	3	3	2	4	9	8	6	7	
Yel.-Green.	8	4	4	9	9	9	4	6	13	9	9	10	9	4	4	4	2	9	6	10	11	3	9	10	
Blue-Green	5	2	1	2	3	5	5	4	2	6	11	13	17	13	17	9	3	4	4	7	6	6	7	6	
Blue.....	2	1	0	5	2	3	4	5	4	5	8	3	3	5	3	12	12	8	4	3	1	1	1	2	
Violet.....	1	0	1	3	5	3	4	2	3	3	1	2	3	2	1	2	10	13	16	21	19	10	2	2	
Purple.....	7	4	2	5	6	4	6	6	6	7	6	8	2	8	2	2	5	0	1	0	0	6	12	16	

B.

Tints	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	Colours
Red.....	7	3	3	4	3	5	5	2	0	4	7	5	2	3	3	2	1	0	0	1	1	5	7	1	
Orange....	3	5	6	5	8	8	10	9	7	10	8	9	2	3	5	2	3	5	2	7	2	2	6	7	
Yellow....	2	2	5	5	3	4	11	5	7	7	7	9	4	4	3	4	3	6	3	2	4	4	6	8	
Yel.-Green	10	8	10	6	7	3	4	9	5	7	7	14	14	13	3	5	3	8	3	1	2	6	8	7	
Blue-Green	6	4	4	4	5	6	9	11	10	7	5	5	12	22	13	5	2	4	3	1	2	4	3	5	
Blue.....	4	6	2	3	3	4	3	6	4	4	6	5	3	5	8	11	12	9	11	8	6	3	0	4	
Violet.....	4	3	0	0	4	4	5	4	6	10	9	8	7	8	2	2	2	4	11	23	22	1	0	0	
Purple.....	3	3	4	5	5	4	8	6	7	8	6	8	4	5	10	0	2	2	3	5	6	17	10	7	

TABLE VII.

SHADES AND COLOURS.

PLEASANT COMBINATIONS.

A.

Colours	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	Shades
Red.....	19	18	18	23	22	30	30	29	29	24	31	22	23	23	19	16	20	18	16	14	19	15	12	14	
Orange ...	26	26	29	26	35	39	31	34	27	27	24	22	25	18	13	16	18	14	23	17	24	19	24	21	
Yellow....	31	29	22	26	26	34	34	30	28	32	22	23	24	19	21	18	24	20	20	18	23	21	21	21	
Yel. Green	24	26	23	27	29	27	29	28	24	23	26	18	25	18	18	16	20	18	16	20	17	23	27	27	
Blue Green	26	18	19	24	20	27	27	21	22	24	19	19	19	16	13	20	18	22	12	17	13	13	25	24	
Blue.....	18	19	20	20	16	19	20	23	22	19	18	16	16	19	11	9	12	15	10	3	8	6	9	8	
Violet	15	11	14	16	14	21	20	12	15	13	15	18	26	18	14	10	9	15	21	12	12	7	8	13	
Purple....	12	19	14	17	23	27	33	39	27	23	26	29	27	29	28	20	17	18	21	18	18	17	21	17	

B

Shades	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	Colours
Red	15	18	22	17	20	35	33	32	17	22	30	21	25	22	16	19	18	11	14	12	14	15	13	17	
Orange....	23	22	30	27	36	37	42	25	19	22	28	14	24	22	25	18	21	16	13	21	17	22	17	28	
Yellow....	28	29	31	27	30	35	35	34	23	26	26	29	25	23	22	25	22	18	17	17	13	33	31	32	
Yel. Green	29	23	25	21	19	33	32	27	18	13	30	19	21	26	15	18	12	14	15	17	14	30	24	24	
Blue Green	30	19	16	19	18	19	17	28	19	17	24	20	18	20	10	19	12	15	15	25	18	28	21	32	
Blue.....	23	17	14	9	16	23	22	22	18	16	18	20	25	21	14	9	13	14	12	11	11	14	19	22	
Violet.....	20	15	14	18	20	26	24	17	20	16	18	19	12	19	11	5	5	11	9	16	20	20	18	19	
Purple.....	11	16	14	16	18	30	30	20	13	17	25	35	25	20	17	7	7	9	8	10	10	23	16	16	

TABLE VIII.

SHADES AND COLOURS.

MOST PLEASANT.

A.

Colours	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	Shades
Red.....	7	8	3	11	7	9	8	5	7	8	11	5	9	10	4	2	2	5	4	3	5	4	4	6	
Orange....	12	8	6	12	8	9	12	8	4	8	6	6	6	3	6	6	4	3	1	0	0	4	3	4	
Yellow....	6	9	8	4	5	11	14	11	6	7	6	3	6	5	5	10	6	8	4	4	9	6	8	8	
Yel.-Green.	14	12	9	10	4	3	12	8	12	8	13	9	8	2	5	4	6	5	5	7	5	9	14	12	
Blue-Green...	6	9	5	9	7	9	11	5	4	9	9	10	7	8	8	8	3	5	3	4	4	4	9	7	
Blue.....	2	1	3	2	5	4	12	12	11	7	3	4	3	8	3	3	4	3	2	0	1	0	1	3	
Violet.....	3	1	1	3	3	5	5	2	4	2	2	4	8	5	1	1	4	6	5	7	6	3	2	2	
Purple.....	7	1	2	4	7	12	10	14	13	6	7	10	8	15	8	3	3	7	7	4	6	6	5	10	

B.

Shades	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	Colours
Red.....	5	6	7	7	7	12	13	8	2	6	17	12	8	9	3	1	4	1	1	3	1	3	5	2	
Orange....	11	5	11	7	9	13	12	6	2	8	6	3	6	13	6	3	4	4	2	5	4	9	6	8	
Yellow....	7	5	8	7	6	11	16	10	5	15	9	8	4	7	9	11	13	11	6	4	1	12	14	11	
Yel.-Green.	8	9	7	6	6	8	6	6	4	11	12	7	8	12	8	8	4	2	3	2	3	8	10	5	
Blue-Green	13	5	5	9	4	2	2	6	8	4	4	7	7	12	4	7	3	4	4	6	4	12	10	9	
Blue.....	6	1	2	2	3	8	4	9	11	5	4	6	7	8	1	2	5	3	4	4	3	3	5	5	
Violet.....	5	4	3	0	0	1	5	7	5	6	7	4	0	8	3	1	0	2	5	6	7	4	6	7	
Purple.....	6	7	1	2	4	5	9	7	6	6	15	14	5	12	3	2	1	1	2	1	4	9	6	6	

maxima distributed over the whole field. The maximum never coincides with the complementary colour. The latter is sometimes even very near the minimum. But in a few cases also it is at a minor maximum.

In one sense the curves are not comparable with those of Miss Baker's, where the colour could never be combined with itself, whilst in our experiments the colour combined with a shade or a tint of itself might make a very good combination. So we see, for instance, that the purples and reddish-purples, which, as everybody knows, are so difficult to match, have their maximum with themselves or their nearest neighbours, and a second maximum with yellow or greenish-yellow. Of course, Miss Baker's curves could show no such thing, as the colours combined with themselves would make no binary combination at all.

In the curves of which Figure II is a sample the frequency of the selection of a tint with the colours is shown. Of course, it must by no means be expected that the curves closely correspond to those of the foregoing series—though they may show similar features, in so far as the colour *quality* is concerned. Thus, for instance, we make the same observation as regards the non-coincidence of maximum and complementary, and we observe again the above mentioned relations of the purple with itself and yellow.

TINTS.	HARMONIZE BEST WITH	HARMONIZE WITH	DO NOT HARMONIZE WITH	
Red	Yellow-green	Violet-purple	Blue and Violet.	Colours in full saturation
Orange	Green	Themselves	Blue.	
Yellow and Yellow-green	Themselves	Yellow-green	Blue.	
Green	Red	Themselves	Orange, Blue.	
Blue	Themselves	Their neighbours	Green, Red.	
Violet	Themselves	Yellow	Red, Blue.	
Purple	Themselves	Yellow	Red, Violet.	

The third series of curves of which Figure III is a specimen shows the harmonic qualities of colours in relation to the shades. Complementarism does not seem to be favoured except in the green and the blue, and partially so in the purple. Here there are sometimes several maxima, which for the red colour

are always in the yellow or yellow-green. The orange and yellow colours have their maxima decidedly with their own shades or with those of near neighbours—a circumstance which might well be expected from the frequency with which, for ornamental purposes in rooms, architecture, etc., we use the combinations of different shades of yellow or orange (brown). As soon as we come toward the green, however, the maximum jumps to the purple, and for the colours 12 and 13 we have the rare case where the maximum closely coincides with the complementary. Thus, while complementary green and purple do not form the most agreeable combination when in full saturation,[1] they do so when the purple is a shade. Similarly we find a maximum for the purple colours (22, 23, 24) in the green (11, 12, 13), though in this case the yellow has still a little greater preference. While we observed that the purple colours harmonize very well with their own tints, we cannot say the same with regard to their relation to their own shades; on the contrary, their own shades are decidedly in the minimum.

Figure IV is an example of the fourth set of curves which indicate the frequency with which the shades were chosen in combination with the colours. Here we make the same observations with regard to the green. It seems to harmonize best with the purple, though in no case is the complementary directly in the maximum. The maxima fall as follows :—

Red	with	Yellow
Orange (Or.-Yellow)	"	Orange-Yellow.
Yellow	"	Purple and Orange.
Yellow-green	"	Orange-yellow.
Bluish-green	"	Purple.
Green	"	Orange-yellow and Purple.
Blue	"	Yellow and Green, and the minimum with itself.
Violet	"	Violet-purple and Yellow.
Purple	"	Yellow and Green.

[1] See Miss Baker's Curves.

What has been stated with reference to the 96 curves of which we could only give four examples will appear equally clear in the following plates, containing Figures V to XX.

These curves correspond to some extent to the combination curves XXV to XXXVI in Miss Baker's first article. In these curves three qualities are always combined, thus, Red stands for one, two and three, Orange for four, five and six, Yellow for seven, eight and nine, Yellow-green for ten, eleven and twelve, Blue-green for thirteen, fourteen and fifteen, Blue for sixteen, seventeen and eighteen, Violet for nineteen, twenty and twenty-one, Purple for twenty-two, twenty-three and twenty-four. The numbers for the ordinates of these curves will be found in Tables v, vi, vii and viii.

Each figure contains four curves, the upper referring to "pleasant" and the lower to "most pleasant" combinations. In Figure V the plain curves refer to the combinations of the tints with the fully saturated red (1, 2, 3); the dotted curves on the other hand represent the combinations of the fully saturated colours with the tint of red (1, 2, 3). The other figures are arranged similarly.

Figures XXI and XXII give the grand total or summation curves. In the former the results of the combinations of colours and tints are represented, whilst the latter refers to colours and shades. Analogous to the foregoing figures the *plain* curves show the degree of harmonizing power of the colours in full saturation, whilst the *dotted* curves indicate the harmonizing capability of the shades and tints. In these curves the striking difference in the behaviour of shades and tints manifests itself at once. For combinations of tints and colours there is a broad maximum in the middle of the spectrum, in the yellow, yellow-green and blue-green. From there the harmonizing power of the tints slopes more or less abruptly down toward the spectral ends, whilst for the colours in combination with tints there are secondary maxima in violet and red, thus leaving the orange and the blue in a decided, and the purple in a less pronounced minimum. The

curve for the "most pleasant" combinations forms in each case almost a copy of that for the pleasant on a smaller scale.

The pleasant curves for the "shades and colours" show a most decided maximum in the orange-yellow and secondary maxima in the green and purple. The deepest drop appears in the blue and violet. This minimum and the secondary maxima are more pronounced for the colours than for the shades. The "most pleasant" curve corresponds well with the "pleasant" in case of the shades, whilst for the colours there are three pointed maxima in the orange-yellow, the yellow-green and the blue-green, the latter being the highest, with decided drops between them.

The summation curves as well as the grand totals of Tables i to iv show that in combination with fully saturated colours shades have a considerable advantage over tints. The pleasant combinations of shades and colours exceed those of tints and colours by 373 which is about 10 per cent., whilst for the most pleasant combinations a corresponding excess of 123 is observed, which amounts to almost 12 per cent.

In Tables ix, x, xi, xii we give a more condensed and consequently a more perspicuous representation of our results. The grouping together of three consecutive qualities is applied here to both sides,—to the colours as well as to the tints and shades. Hence it is quite easy to survey the 64 fields of the tables. Thus, for instance, in Table ix the first horizontal row of numbers indicates that the power of harmonization of red with the tints of the eight qualities is greatest for yellow-green, less great for yellow and for blue-green, still less for orange, red, blue and purple and smallest for violet.

The first vertical column, on the other hand, shows that the tint of red when combined with the colours in full saturation harmonizes equally well with yellow-green and purple, somewhat less with blue-green, yellow and red, still less with orange and violet and least with blue. So with the other columns. From the whole table one can see that with regard to the combination of *tints* and colours the gravitation of pleasantness is to the middle of the spectrum; whilst from Table

xi it can easily be deduced that the gravity centre for pleasantness for *shades* and colours is decidedly with the "warm" colours (orange and yellow). The question in how far the colours agree with their own tints and shades can also be settled by these tables., The best to agree with their own tints, as Table ix shows, are blue-green and violet, next comes yellow-green, then yellow, blue, purple, and the least, red. A glance at Table x shows that the same result can be ascertained from the "most pleasant" judgments. Tables xi and xii show that it is quite different with regard to shades. The colours which agree best with their own shades are orange and yellow.

TABLE IX.

TINTS AND COLOURS.—"PLEASANT."

Colours.	R.	Or.	Y.	Y.G.	B.	B.G.	V.	P.	Tints.
R.....	38	56	66	81	60	36	19	20	376
Or.....	31	63	54	52	57	46	22	36	361
Y.....	40	63	70	71	84	74	68	62	532
Y.G.....	57	67	82	87	56	47	63	56	515
B.G.....	44	58	66	89	102	60	57	62	538
B.....	20	40	61	54	57	67	41	16	356
V.....	27	55	49	59	50	69	104	31	444
P.....	57	59	73	60	50	33	13	65	410
	314	461	521	553	516	432	387	348	3532

TABLE X.

TINTS AND COLOURS.—" MOST PLEASANT."

Colours.	R.	Or.	Y.	Y.G.	B.G.	B.	V.	P.	Tints.
R.....	13	14	9	28	14	12	7	10	107
Or.....	12	21	12	16	15	10	8	14	108
Y.....	7	26	23	18	30	13	15	21	153
Y.G.....	16	27	23	28	17	15	27	22	175
B.G.....	8	10	11	30	47	16	17	19	158
B.....	3	10	13	16	11	32	8	4	97
V..	2	11	9	6	6	25	56	14	129
P.....	13	15	18	21	12	7	1	34	121
	74	134	118	163	152	120	139	148	1048

TABLE XI.

SHADES AND COLOURS.—" PLEASANT."

Colours.	R.	Or.	Y	Y.G.	B.G.	B.	V.	P.	Shade
R.....	55	75	88	77	65	54	49	41	50
Or.....	72	100	92	73	56	48	64	64	56
Y.....	82	86	92	77	64	62	61	63	58
Y.G.....	73	74	81	67	61	54	53	77	54
B.G.....	63	71	70	62	48	60	42	62	47
B.....	48	55	65	44	46	36	21	23	33
V.....	40	51	47	46	58	34	45	28	34
P.....	45	67	99	78	84	55	57	55	54
	478	579	634	524	482	403	392	413	390

TABLE XII.

SHADES AND COLOURS.—" MOST PLEASANT."

Colours.	R.	Or.	Y.	Y.G.	B.G.	B.	V.	P.	Shade
R.....	18	27	20	24	23	9	12	14	14
Or.....	26	29	24	20	15	13	1	11	13
Y.....	23	20	31	16	16	24	17	22	16
Y.G.....	35	17	32	30	15	15	17	35	19
B.G.....	20	25	20	28	23	16	11	20	16
B.....	6	11	35	14	14	10	3	4	9
V.....	5	11	11	8	14	11	18	7	8
P.....	10	23	37	23	31	13	17	21	17
	143	163	210	163	151	111	96	134	117

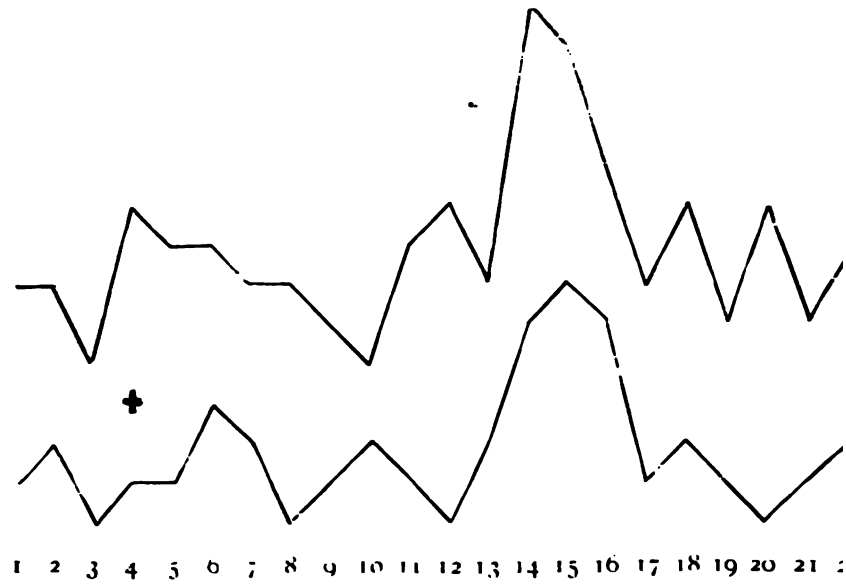


FIG. I.—COLOUR 15 WITH TINTS

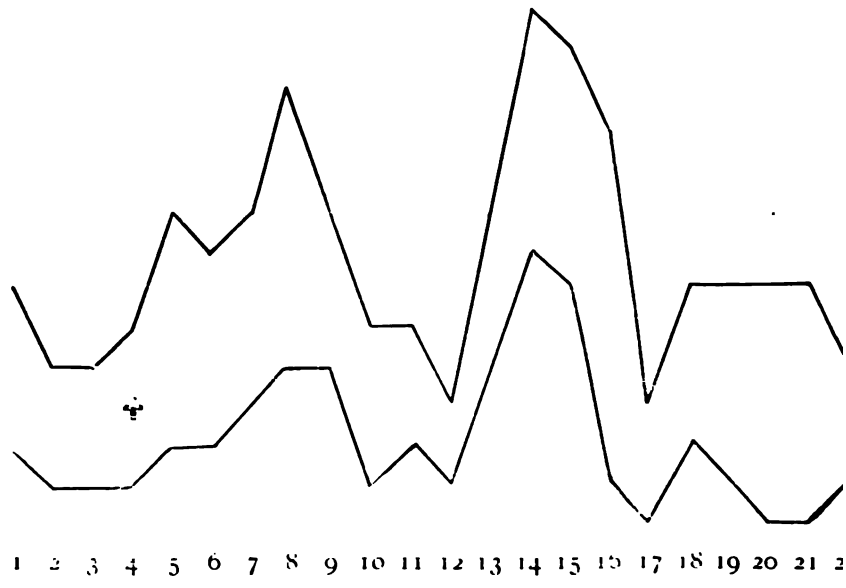


FIG. II.– TINT 15 WITH COLOURS

FIG. III.—COLOUR 15 WITH SHADES

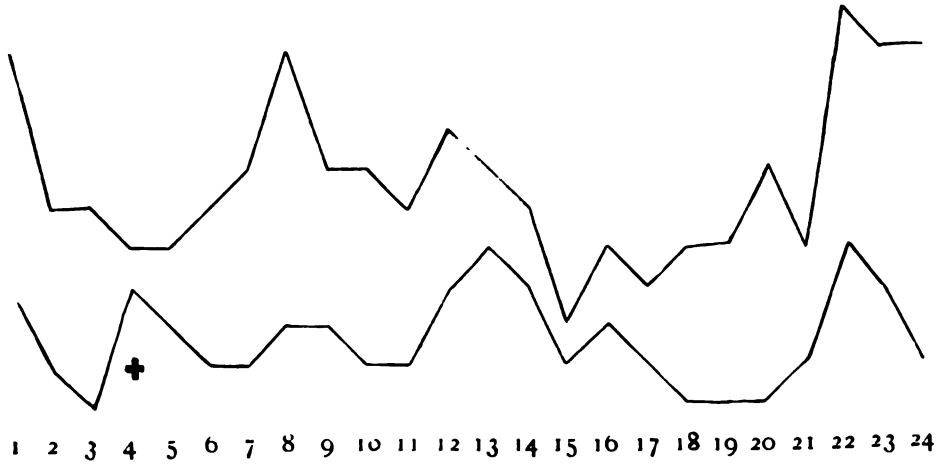


FIG. IV.—SHADE 15 WITH COLOURS

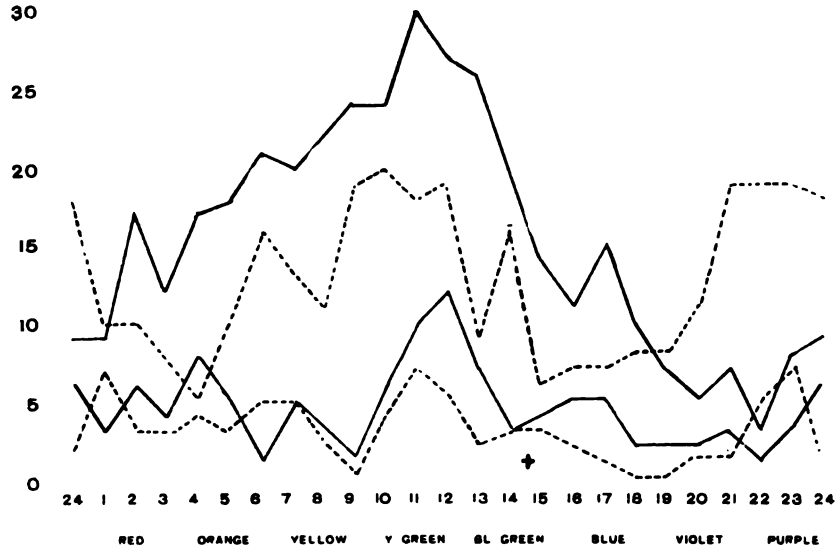


FIG. V.—RED, TINTS AND COLOURS

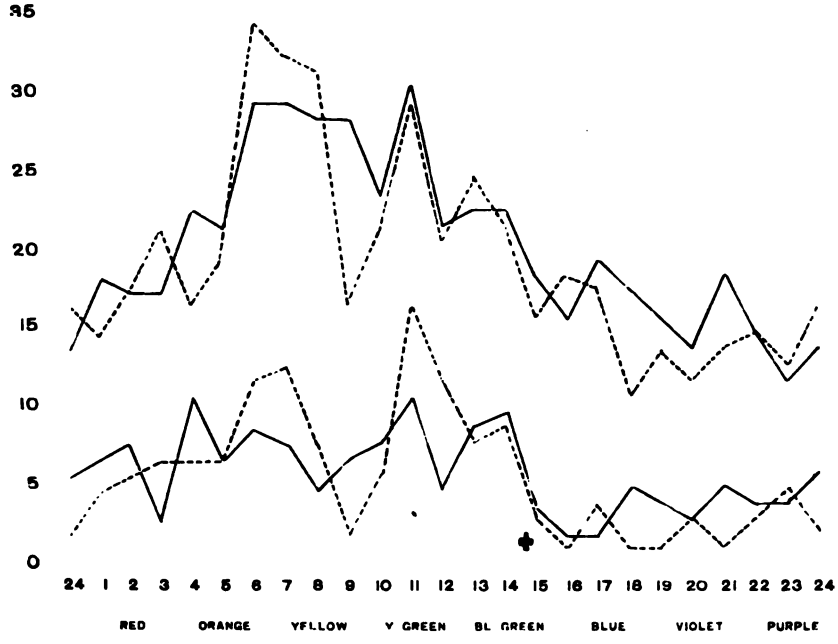


FIG. VI.—RED, SHADES AND COLOURS

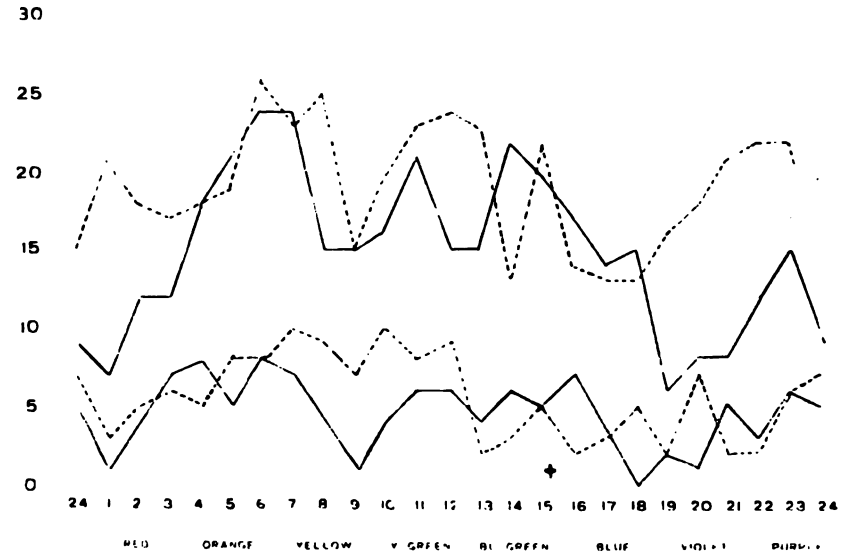


FIG. VII.—ORANGE, TINTS AND COLOURS

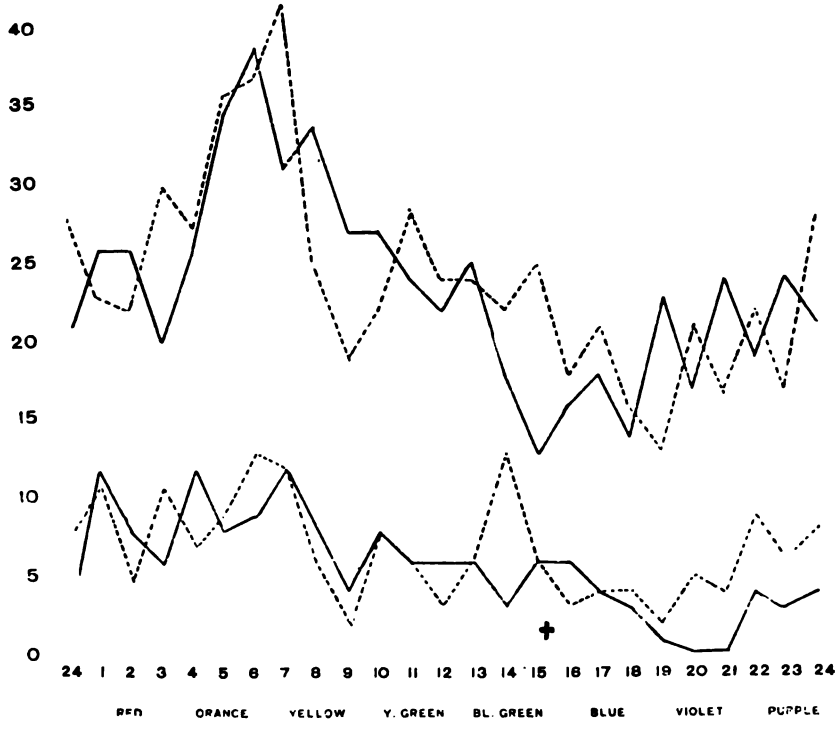


FIG. VIII.—ORANGE, SHADES AND COLOURS

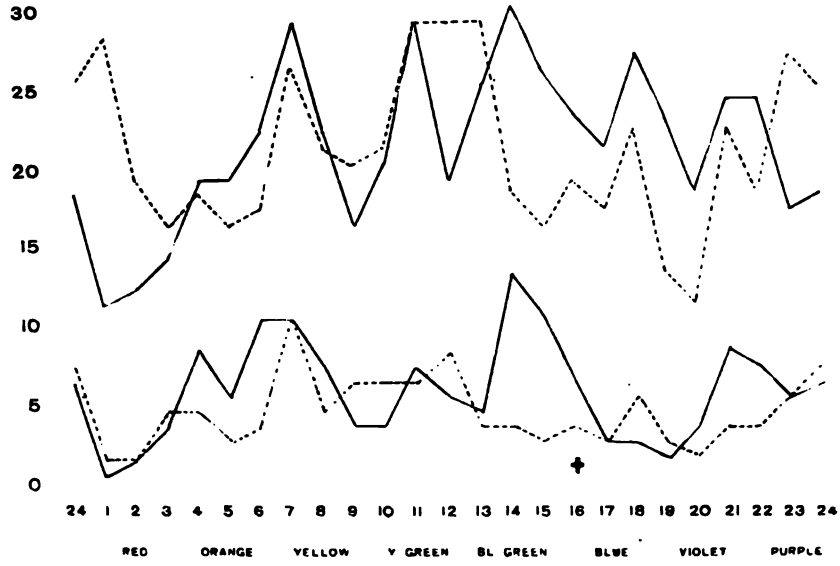


FIG. IX.—YELLOW, TINTS AND COLOURS

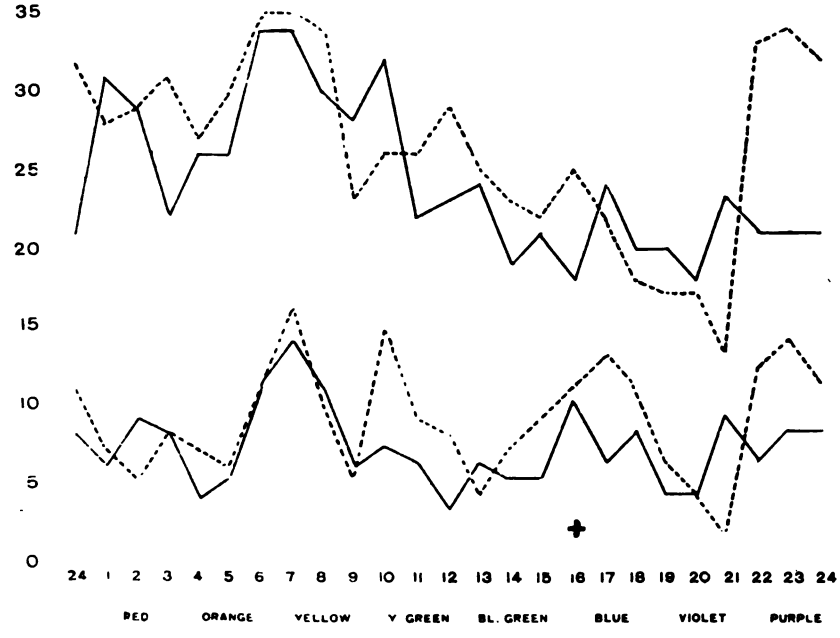


FIG. X.—YELLOW, SHADES AND COLOURS

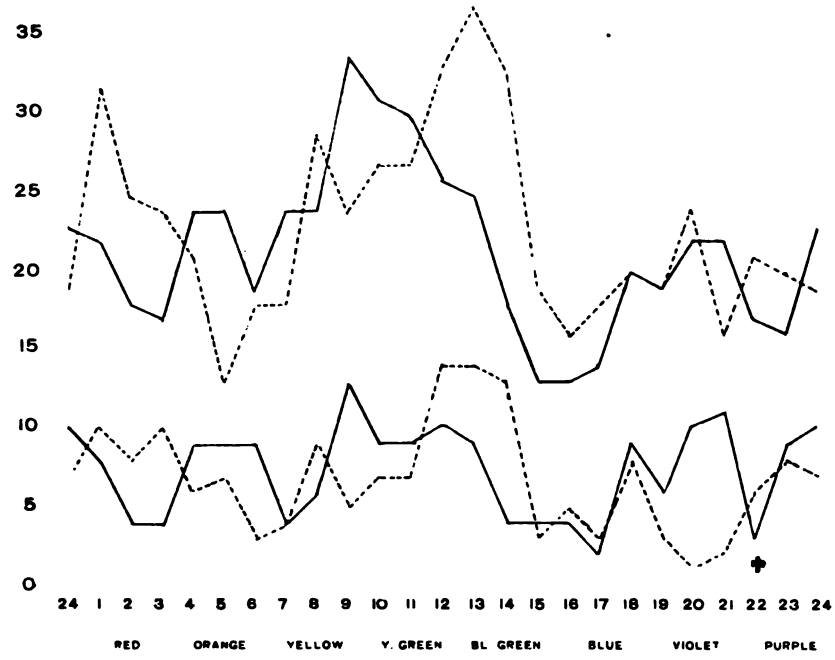


FIG. XI.—YELLOW-GREEN, TINTS AND COLOURS

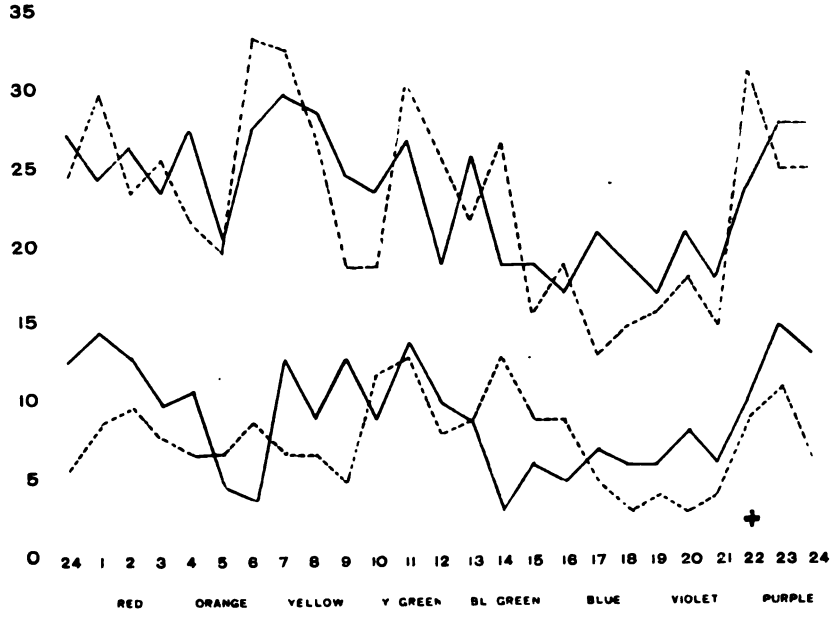


FIG. XII.—YELLOW-GREEN, SHADES AND COLOURS

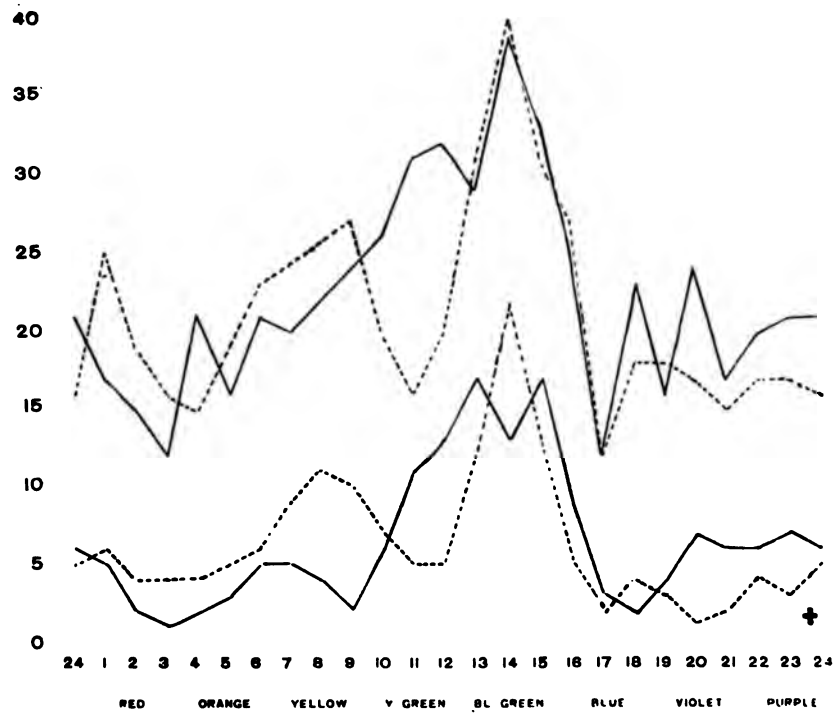


FIG. XIII.—BLUE-GREEN, TINTS AND COLOURS

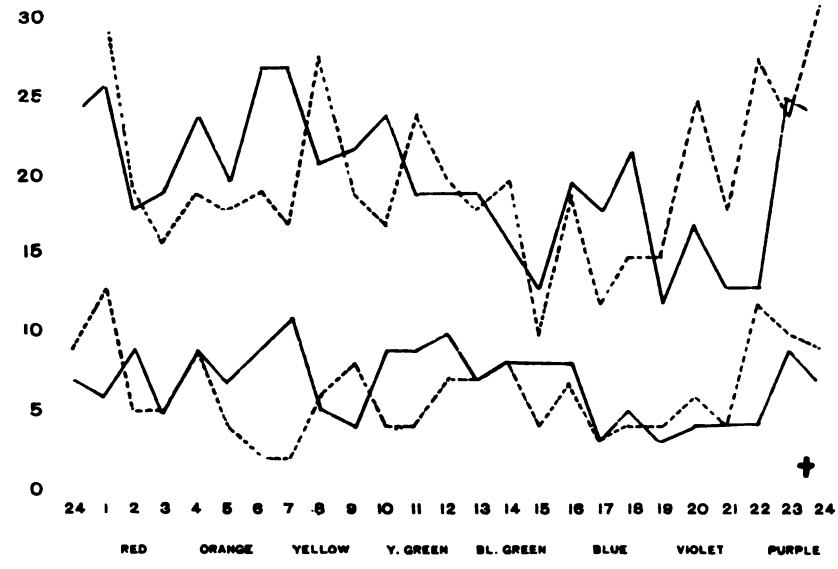


FIG. XIV.—BLUE-GREEN, SHADES AND COLOURS

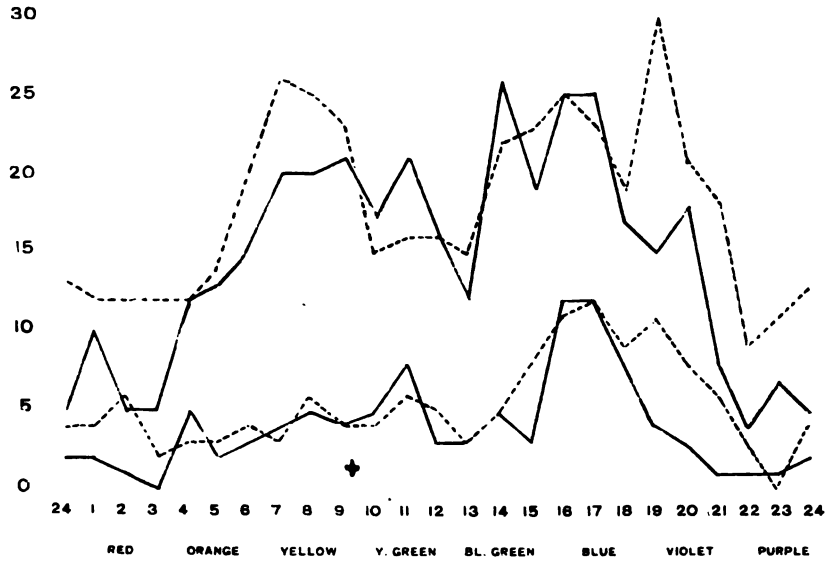


FIG. XV.—BLUE, TINTS AND COLOURS

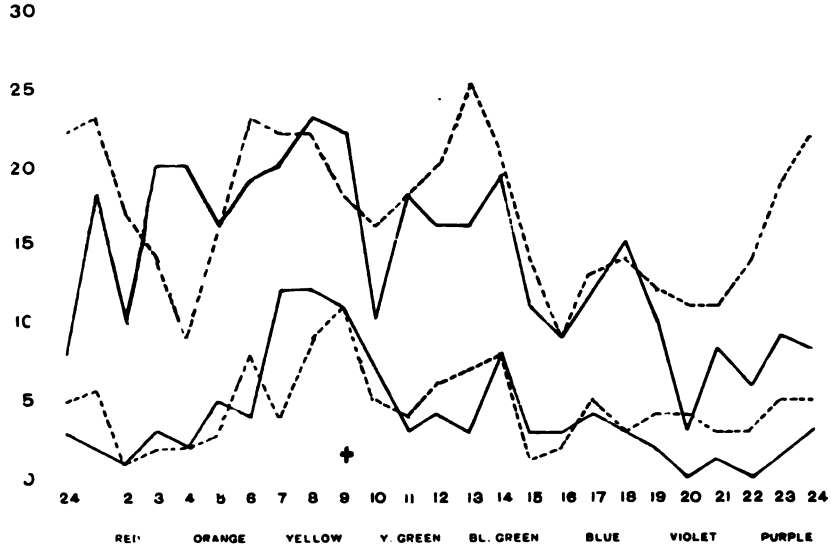


FIG. XVI.—BLUE, SHADES AND COLOURS

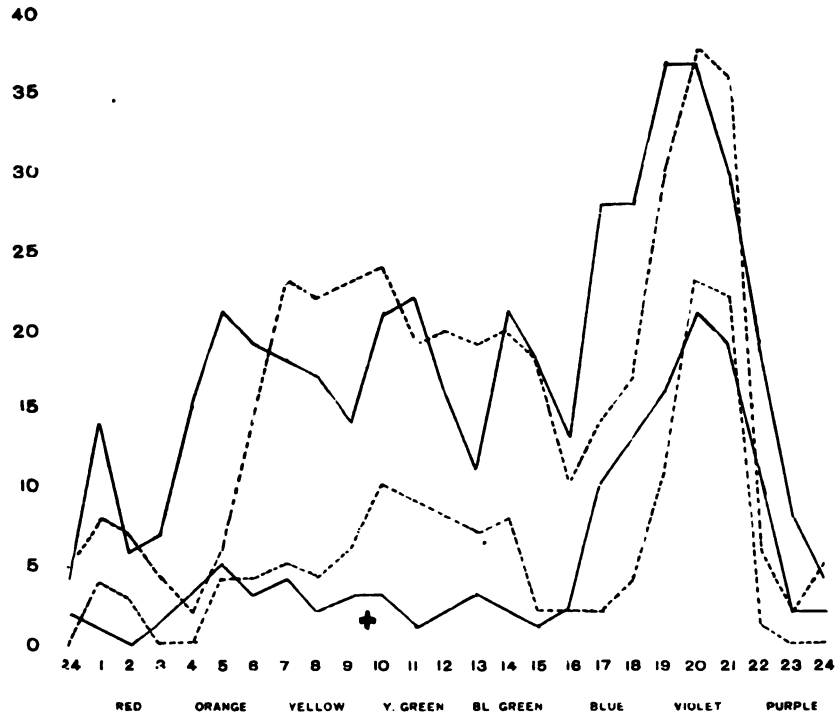


FIG. XVII.—VIOLET, TINTS AND COLOURS

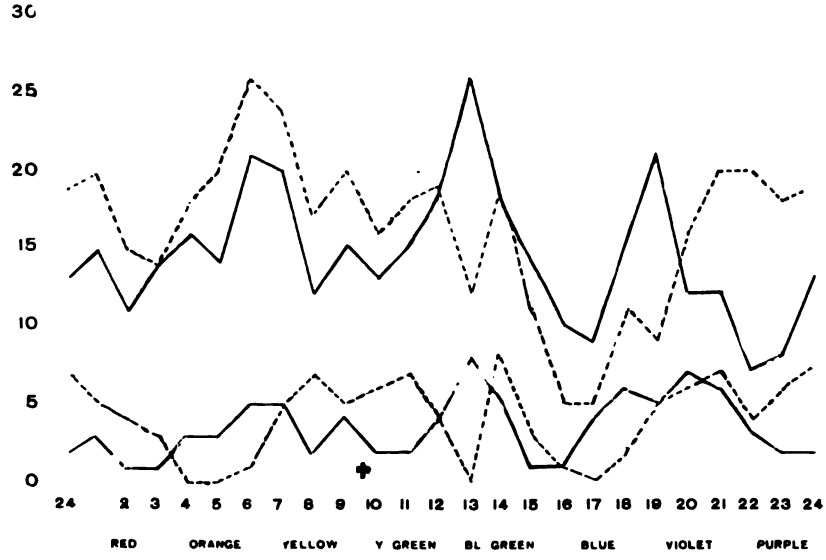


FIG. XVIII.—VIOLET, SHADES AND COLOURS

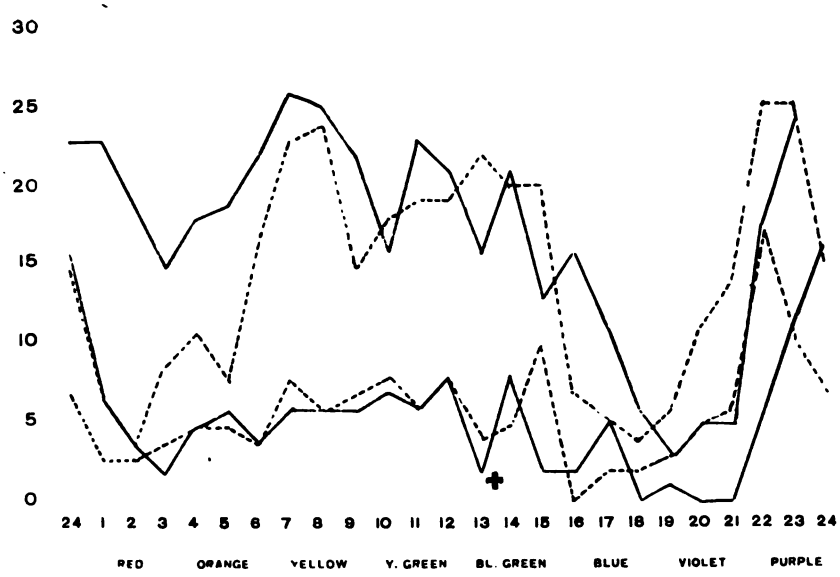


FIG. XIX.—PURPLE, TINTS AND COLOURS

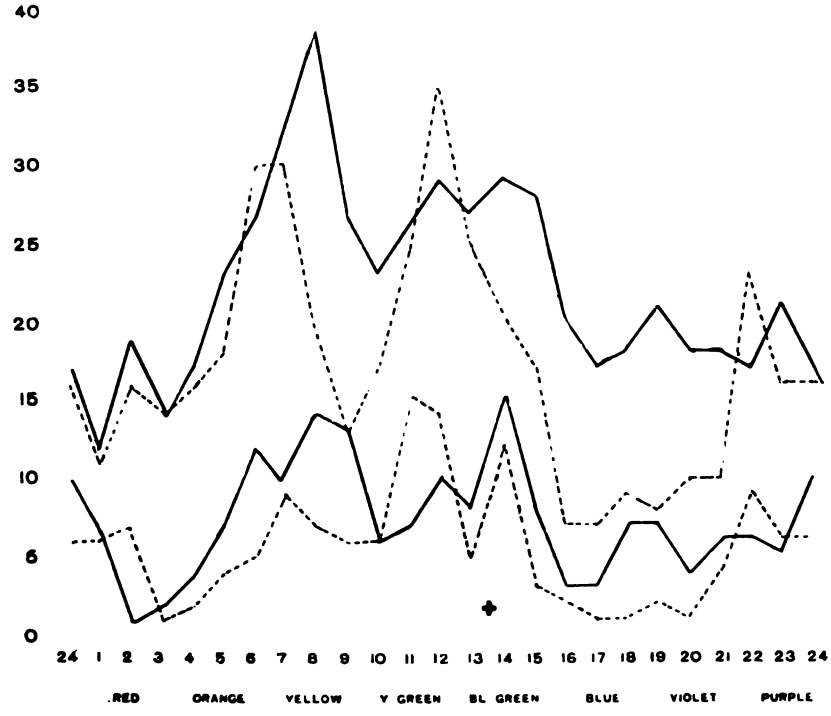


FIG. XX.—PURPLE, SHADES AND COLOURS

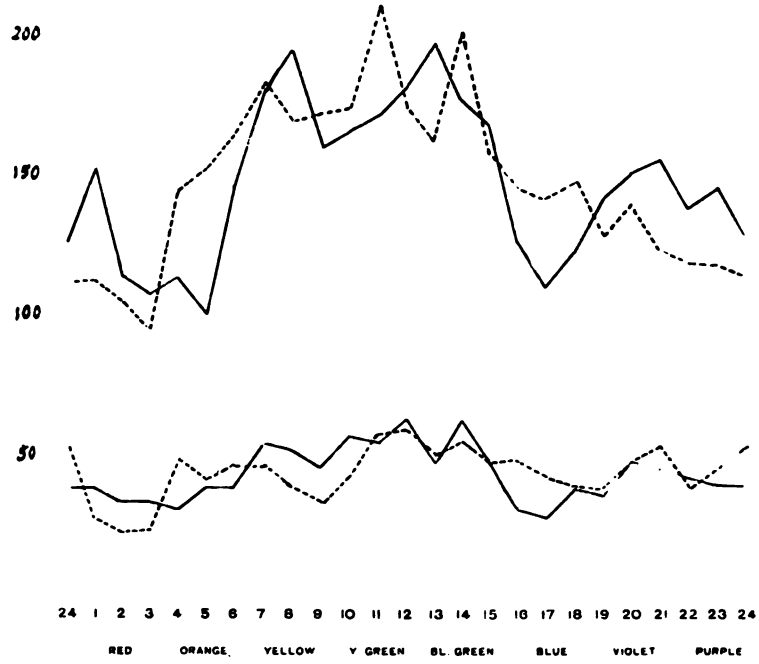


FIG. XXI.—SUMMATION CURVE, TINTS AND COLOURS

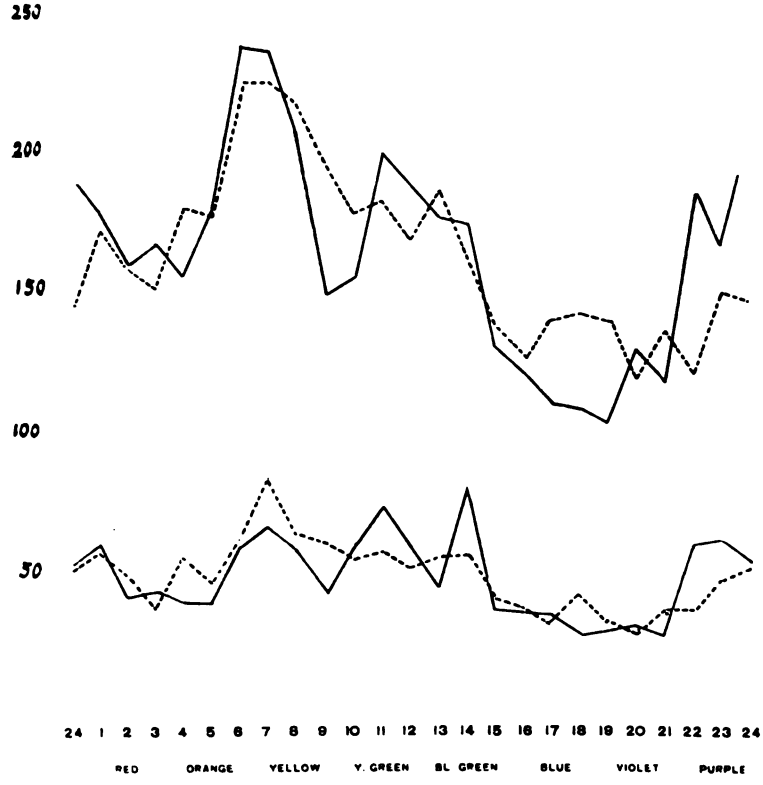


FIG. XXII.—SUMMATION CURVE, SHADES AND COLOURS

STEREOSCOPIC VISION

AND ITS RELATION TO INTENSITY AND QUALITY OF LIGHT SENSATION

SECOND ARTICLE

STEREOSCOPIC VISION AND QUALITY OF LIGHT SENSATION

BY

T. R. ROBINSON, B.A.

STEREOSCOPIC VISION IN ITS RELATION TO QUALITY OF LIGHT SENSATION.

In the former article [1] an account was given of some experiments upon the application to the two retinas of light stimuli of different *intensity*. There are some phenomena of equal interest which occur when the respective parts of the stimulus are of different *quality*. The presentation of different colour stimuli simultaneously to the two eyes may have various results, according to the degree of difference in the quality of the stimuli. In the experiments now to be described the following questions were kept in view :

(1) Will the results obtained by the previously reported experiments with uncoloured light be essentially altered by the introduction of the colour factor ?

(2) What are the limits of possibility for binocular mixture of qualitatively different retinal impressions ?

[1] University of Toronto Studies, Psychological Series, Vol. ii, No. 2.

(3) How is such binocular mixture of colours related to the stereoscopic combination of the retinal images, i.e., do differences of colour affect the stereoscopic combination, or, on the other hand, does the stereoscopic combination facilitate or hinder the binocular mixture of colours ?

I. COMPARISON OF MONOCULAR AND BINOCULAR INTENSITIES IN COLOURED LIGHT

A few experiments were made upon this point in the course of an investigation by the author in connection with Fechner's paradox, [1] referred to more fully in the preceding article. Those experiments, however, were comparatively few in number, and made with only one absolute intensity, so that the results were not conclusive. The chief differences from the results with white light were that the judgments were more difficult and less decided, and that the region of equality in intensity between monocular and binocular vision extended over a wider field. The differences between the results of the same two observers were noticeably greater than with

[1] American Journal of Psychology, Vol. vii, No. 1, pp. 9 etc.

uncoloured light, perhaps because the intensity values of the colours were not the same for different observers.

A further series of experiments has been made, following a modification of the former method. The apparatus was the same as that used for the experiments in binocular lustre,[1] except that the objects observed were plane coloured surfaces instead of stereoscopic objects. On each side were two brightly illuminated coloured surfaces, which were combined by means of the stereoscope. Before one of them the episkotister-disc was revolved, so that the surfaces differed in brightness, while remaining similar in all other respects. The difference in brightness could, of course, be varied by re-adjusting the disc. The colour was furnished by coloured gelatine or thin glass plates placed over the openings in the front screen of the apparatus, white paper being placed opposite them on the screen or wall at the back. The experiments were made in a dark room by two observers, who took turns in operating for each other. They began in each case with monocular vision, i.e., by looking through the stereoscope with the shutter covering the lens before which the disc revolved. Then, after the observer had looked for a few moments, the shutter was opened, and he at once reported whether the brightness was equal to, greater or less than that of monocular vision. A series was made by increasing the opening of the disc until the raising of the shutter plainly resulted in an increase of brightness, then by decreasing the opening until monocular and binocular intensities appeared equal, and still further until the opening of the shutter caused a just noticeable decrease of brightness. Then the opening of the disc was gradually widened till the equal region was reached again and still further till, on the opening of the shutter, there was a just noticeable increase of brightness. In the results of observer "J" the average of the "equal" judgments is given for each series. The results of observer "H" were calculated a little differently, taking the average of the degrees of opening of

[1] University of Toronto Studies, Psychological Series, Vol. ii. No. 2, p. 77.

the disc when the judgments were "brighter," "darker" and "equal," the values for "brighter" and "darker" being regarded as the limits for the region of equality. The colours used were from near the middle and ends of the spectrum, being respectively red, green and blue. Similar series were also made with white light for the purpose of comparison. The wave-lengths of the respective colours were approximately as follows : red 615-740$\mu\mu$, green 480-560$\mu\mu$, blue 440-500$\mu\mu$.

Certain special difficulties were found in experimenting with coloured light. First, there was the necessity of abstracting intensity changes from saturation changes with increasing or decreasing illumination. This made the judgments in some cases very difficult, especially with the blue light. When the opening of the disc was very small there was competition of the vision fields, that of the darkened eye having either no colour, or a slight tinge of yellow, due to binocular contrast. Secondly, the disturbing effect of after-images had to be more carefully guarded against. Again, each observer found himself able to distinguish differences of brightness more readily with certain colours than with others. Thus the discrimination of "H" was best with green, that of "J" with red. A further obstacle in the way of comparing the results with different colours is that the same illumination could not be used for all the colours. With the red it was found necessary to use a 100 c.p. lamp, as with weaker illumination the "equal" limits could not be passed in both directions. On the other hand this very bright light had certain disturbing effects on account of which it was not used with the other colours; the fatigue of the eye was very great, and the after-images gave more trouble. Observer "J" noted, however, in spite of these hindrances, that discrimination was less difficult with red than with white light.

The results of these experiments are given in Tables I and II. They show the same general dependence of the relation of monocular to binocular intensity upon the absolute intensity of illumination as is shown in the experiments with uncoloured light. Difference of quality, therefore, does not apparently

affect the intensity relations. Where the brightness of the coloured light is approximately the same as with red and green, the results show very little difference. On the other hand, the very great difference of average values between blue and red or green may perhaps not be due solely to the difference of brightness. This indeed seems probable in view of the fact that in the former experiments, where the colours were of equal brightness, the values for blue were with both observers higher than those for red.

TABLE I.—OBSERVER H.

Light Used			Amount of Light in the Second Eye which has no effect on Brightness of Common Visual Field		
Quality	Illumination	Intensity Photometrically Measured	Opening of the Disc	Units of Intensity	Ratio of the Light in the Other Eye
Blue.....	50 c.p. lamp	1	90°	.25	.25
Green.....	50 c.p. lamp	9.69	253°	6.78	.70
Red.....	100 c.p. lamp	10.00	235°	6.50	.65
White....	16 c.p. lamp.	22.50	267°	16.65	.74

TABLE II.—OBSERVER J.

Light Used			Amount of Light in the Second Eye which has no effect on Brightness of Common Visual Field		
Quality	Illumination	Intensity Photometrically Measured	Opening of the Disc	Units of Intensity	Ratio of the Light in the Other Eye
Blue.....	50 c.p. lamp.	1	114°	.31	.31
Green.....	50 c.p. lamp.	9.69	255°	6.86	.70
Red.....	100 c.p. lamp.	10.00	247	6.86	.68
White. ..	16 c.p. lamp.	22.50	267	16.65	.74

II. BINOCULAR MIXTURE OF COLOURS

The experiments to be described in this section were conducted with the purpose of discovering the effects of various degrees of difference in quality between the two retinal impressions. There were four series of experiments : (1) the

first series was made with small coloured surfaces upon a dark field; (2) in the next series stereoscopic figures against a dark ground were observed, the impressions in the respective eyes being differently coloured; (3) in the third case, stereoscopic figures were employed, and one retinal image was coloured, the other uncoloured; (4) in the fourth series, an entirely different method was employed, and the colours occupied the whole vision field, instead of only a part of it.

(1) *Plane coloured surfaces upon a dark field.* The colours used were approximately spectrally pure, the surfaces observed being of Milton-Bradley coloured paper, illuminated by light which passed through combinations of coloured gelatines. A stereoscopic picture of the apparatus employed is shown in Fig. 1, and a schematic representation of it, as seen from above, is given in Fig. 2. Across the back of a table, A, 66 cm. long and 42 cm. wide, is fixed a screen, B, of the same width as the table and 65 cm. high; 18 cm. before this screen is another, C, of similar dimensions. Between these two screens, at the middle of the table there is a partition, D, to enable the right and left halves of the rear screen to be illuminated independently of each other. The top of the table and the surfaces of the screens and of the partition are a dead black. Upon the rear screen, two thin wooden discs, E, E, one on each side of the partition, are fastened by screws at the centre only, so that they may be turned at will. The surfaces of these discs are divided into seven sectors, covered with Milton-Bradley coloured papers. The discs are so placed that the inner edge of each comes close to the dividing partition. In the centre of the front screen, 25 mm. apart, and one on each side of the partition, are two openings, a, a, 45 mm. square, through each of which can be seen a portion of one sector only of the colour disc opposite it. Turning the discs thus brings each colour in succession before the openings. For illuminating the discs there are employed two sheet iron tubes, F, F, 15 cm. square, and 91 cm. long. The front ends of these tubes are inserted through openings which they exactly fit in the front screen. The inner edges of the tubes

are 16 cm. apart, and they are on a level with the portions of the discs visible through the smaller openings before described. The latter are thus directly between the openings which admit the ends of the tubes. In order that the tubes may not interfere with the position of the observer before the apparatus, they are placed at an angle so that their outer ends are widely apart. In each tube is a moveable block, fitting the inside of the tube, to the front of which is attached a socket for an incandescent electric lamp. The upper side of each tube has a narrow slit, b, b, running nearly its whole length, through which projects an attachment to the block for affixing the wires which connect with the light socket, and a screw, c,c, for fixing the block at any desired distance from the ends of the tube. The front end of each tube is fitted with a groove, d,d, into which were slipped frames containing the combinations of gelatines through which the light passed before falling upon the sectors of the discs. During the experiments all other light was excluded from the room. By the use of varying combinations of papers and gelatines, the spectrum was divided into twelve approximately equal divisions. These colours are the same as were used by Miss Baker in her work upon the aesthetics of colour combinations. Their spectroscopical analysis is given below.

SPECTROSCOPICAL ANALYSIS OF COLOURS.

Name of Colour	With Narrow Slit		With Wide Slit	
	Visible part of Spectrum in $\mu\mu$	Region of greatest intensity in $\mu\mu$	Visible part of Spectrum in $\mu\mu$	Region of greatest intensity in $\mu\mu$
Red	665(?)–592.5	635–610	672.5(?)–580	657.5–615
Orange-Red	622.5–582.5	612.5–592.5	635–580	622.5–592.5
Orange	607.5–552.5	585–562.5	622.5–547.5	607.5–562.5
Orange-Yellow	587.5–547.5	562.5–557.5	617.5–537.5	602.5–555
Yellow	580–512.5	562.5–535	615–492.5	587.5–555
Yellow-Green	565–497.5	535–525	580–480	555–530
Green	542.5–492.5	530–507.5	570–480	537.5–517.5
Green-Blue	525–472.5	512.5–495	550–447.5	525–502.5
Blue	570–460	492.5–475	535–445	572.5–492.5
Violet	482.5–432.5	470–462.5	497.5–430	475–455
Violet-Purple	687.5–665 485–440	462.5–455	700–665 487.5–430	470–452.5
Purple	680–645 480–430		680–635 497.5–430	475–460

Their complementary relations are also stated very fully in Miss Baker's article.[1] The purpose of the tubes containing the moveable lamps was to equalize the intensities of the two colours by adjusting the distances from them of the lamps. To facilitate this adjustment a certain intensity of the green-blue, a colour of medium intensity, was taken as the normal, and the positions of the lamps required for the various colours in order to give intensities equal to it were found and marked on the tubes. In a few cases, where one gelatine combination was very much more translucent than the other, the length of the tubes was found insufficient, and either a stronger light had to be used for the duller colour or a sheet of white tissue paper placed before the front of the other tube. The lamps commonly used throughout were 32 c.p. A moveable block was placed upon the front of the table in a groove which enabled it to slide backward and forward. To this block was attached an upright upon which was fixed, at the height of the openings in the screen, the hood of an ordinary stereoscope, G, in which the glasses had been replaced by others of a somewhat longer focal distance.

In the experiments the observer takes his seat in front of the apparatus. There are then before him in the darkened room two small square coloured surfaces, of different colours, but equally bright. Putting his head into the hood of the stereoscope, he adjusts the latter so that the two coloured surfaces completely coincide. All the facts regarding the colour of the surface seen are then noted, and the colour presented to one of the eyes remaining the same, that before the other is changed, and a new observation made. This is repeated till the constant colour has been combined with each of the other colours used. Then another colour is taken as the constant colour, and each of the others combined with it. To vary still further the conditions, with some observers each colour was presented to each of the eyes of the observer as the constant colour, so that it was twice combined with each

[1] University of Toronto Studies, Psychological Series, Vol. ii, No. 1, p. 16.

of the other colours. Four combinations of each colour with each other colour were thus effected for each observer, each colour being presented to each eye once as the constant colour, and once as one of the changing series. With other observers the position of the constant colour was changed from right to left or *vice versa* after each series, but only one series was made for each colour. So that with these observers only two combinations of each colour with each other colour were obtained. Tables III to VIII give the combined results of six observers, with four of whom the former method was followed, with two the latter; so that in the experiments which these tables summarize each of the twelve colours has been combined with each of the others twenty times.

TABLE III.—COMPLETE RIVALRY.
i.e., BOTH COLOURS UNCHANGED.

	R	OR	O	OY	Y	YG	G	GB	B	V	VP	P	
R.....		0	0	0	0	4	6	10	10	9	2	1	42
OR.....	0	..	0	0	1	2	4	10	7	7	2	2	35
O.....	0	0	..	0	0	1	3	6	8	3	4	3	28
OY.....	0	0	0	0	0	0	3	8	9	4	2	6	32
Y.....	0	1	0	0	..	0	2	4	7	2	1	6	23
YG.....	4	2	1	0	0	..	0	1	7	1	3	4	23
G.....	6	4	3	3	2	0	..	0	1	2	0	4	25
GB.....	10	10	6	8	4	1	0	..	0	0	0	1	40
B.....	10	7	8	9	7	7	1	0	..	0	0	3	52
V.....	9	7	3	4	2	1	2	0	0	..	0	0	28
VP.....	2	2	4	2	1	3	0	0	0	0	..	0	14
P.....	1	2	3	6	6	4	4	1	3	0	0	..	30
	42	35	28	32	23	23	25	40	52	28	14	30	372

TABLE IV.—PARTIAL RIVALRY,
i.e., RIVALRY OF THE VISION FIELDS, BUT WITH ONE OR BOTH COLOURS MODIFIED OR WEAKENED.

	R	OR	O	OY	Y	YG	G	GB	B	V	VP	P	
R.....	..	0	0	0	7	14	11	10	9	10	4	1	66
OR.....	0	..	0	0	2	10	10	8	10	11	5	2	58
O.....	0	0	..	0	0	2	9	10	8	13	7	6	55
OY.....	0	0	0	..	0	0	7	7	7	9	9	5	44
Y.....	7	2	0	0	..	0	1	9	8	11	12	12	62
YG.....	14	10	2	0	0	..	0	3	7	10	13	11	70
G.....	11	10	9	7	1	0	..	1	8	8	17	13	85
GB.....	10	8	10	7	9	3	1	..	0	0	6	13	67
B.....	9	10	8	7	8	7	8	0	..	0	2	9	68
V.....	10	11	13	9	11	10	8	0	0	..	0	3	75
VP.....	4	5	7	9	12	13	17	6	2	0	..	0	75
P.....	1	2	6	5	12	11	13	13	9	3	0	..	75
	66	58	55	44	62	70	85	67	68	75	75	75	800

TABLE V.—INCONSTANT MIXTURE.

COMBINATIONS YIELDING A COLOUR WHICH IS A MIXTURE OF THE TWO MONOCULARLY SEEN, BUT INCONSTANT.

	R	OR	O	OY	Y	YG	G	GB	B	V	VP	P	
R.....	..	0	1	2	6	1	2	0	1	0	9	4	26
OR.....	0	..	1	1	3	2	5	1	2	2	7	4	28
O.....	1	1	..	0	1	4	2	2	4	3	5	4	27
OY.....	2	1	0	..	0	6	5	2	4	5	2	3	30
Y.....	6	3	1	0	..	2	5	4	5	4	5	2	37
YG.....	1	2	4	6	2	..	1	7	5	5	3	3	39
G.....	2	5	2	5	5	1	..	4	6	3	2	3	38
GB.....	0	1	2	2	4	7	4	..	0	5	4	4	33
B.....	1	2	4	4	5	5	6	0	..	0	4	5	36
V.....	0	2	3	5	4	5	3	5	0	..	1	8	36
VP.....	9	7	5	2	5	3	2	4	4	1	..	3	45
P.....	4	4	4	3	2	3	3	4	5	8	3	..	43
	26	28	27	30	37	39	38	33	36	36	45	43	418

TABLE VI.—COMPLETE MIXTURE.

	R	OR	O	OY	Y	YG	G	GB	B	V	VP	P	
R.....	..	20	19	18	7	1	1	0	0	1	5	14	86
OR.....	20	..	19	19	14	6	1	1	1	0	6	12	99
O.....	19	19	..	20	19	13	6	2	0	1	4	7	110
OY.....	18	19	20	..	20	14	5	3	0	2	7	6	114
Y.....	7	14	19	20	..	18	12	3	0	3	2	0	98
YG.....	1	6	13	14	18	..	19	9	1	4	1	2	88
G.....	1	1	6	5	12	19	..	15	5	7	1	0	72
GB.....	0	1	2	3	3	9	15	..	20	15	10	2	80
B.....	0	1	0	0	0	1	5	20	..	20	14	3	64
V.....	1	0	1	2	3	4	7	15	20	..	19	9	81
VP.....	5	6	4	7	2	1	1	10	14	19	..	17	86
P.....	14	12	7	6	0	2	0	2	3	9	17	..	72
	86	99	110	114	98	88	72	80	64	81	86	72	1050

TABLE VII.—SUMMARY OF NUMBER OF CASES OF THE RESPECTIVE PHENOMENA FOR EACH COLOUR.

	Complete Rivalry.	Partial Rivalry.	Inconstant Mixture.	Complete Mixture.	
R.....	42	66	26	86	220
OR....	35	58	28	99	220
O.....	28	55	27	110	220
OY....	32	44	30	114	220
Y.....	23	62	37	98	220
YG....	23	70	39	88	220
G.....	25	85	38	72	220
GB....	40	67	33	80	220
B.....	52	68	36	64	220
V.....	28	75	36	81	220
VP....	14	75	45	86	220
P.....	30	75	43	72	220
	372	800	418	1050	2640

TABLE VIII.—NUMBER OF OTHER COLOURS WITH WHICH THE VARIOUS PHENOMENA OCCUR FOR EACH COLOUR.

	Complete Rivalry.	Partial Rivalry.	Inconstant Mixture.	Complete Mixture.
R.....	7	8	8	9
OR.....	8	8	10	10
O.....	7	7	10	10
OY.....	5	6	9	10
Y.....	7	8	10	11
YG.....	8	8	11	10
G.....	8	10	11	10
GB.....	7	9	9	7
B.....	8	9	9	7
V.....	7	8	9	10
VP.....	6	9	11	11
P.....	9	10	11	9
	87	101	118	114

(2) *Stereoscopic figures upon a dark field.* In the experiments thus far recorded, the objects observed, though combined by means of the stereoscope, were simply plane surfaces differently coloured. The question naturally presented itself in connection with this method, whether the results would be different if three-dimensional figures were used instead of plane surfaces. There are, indeed, two questions of interest here, (1) whether the binocular mixture of colours is facilitated or impeded, the rivalry of the vision-fields intensified or lessened, by the effort of combining the outlines into a three-dimensional figure, (2) the question of the effect which differences of colour have upon the stereoscopic combination of the figures. In investigating these points, it was, of course, desirable that the method followed should conform as nearly as possible to that of the former series of experiments. Accordingly the same apparatus and the same colours were used, but over the openings for observation in the front of the apparatus small squares of thin plate glass were placed, upon which the stereoscopic figures were etched. The glass surrounding the drawing was blackened to prevent the transmission or reflection of light. Three pairs of outline drawings were used, one forming a transparent octahedral crystal, another

on opaque hexagonal crystal, and the third a truncated pyramid, with the summit projecting toward the observer. The etchings were made in two ways, some being on clear glass with frosted lines, others on frosted glass with the lines clear. These figures are reproduced, as nearly as possible as they were used, in Figs. 3 to 5. The experiments were conducted in the same manner as those with plane surfaces, the number of combinations of each colour with each other colour being in this case sixteen. The results as regards the mixture of colours are shown in Tables IX to XIV. Tables XV to XIX show the effect upon the stereoscopic combination of the differences in the colour of the objects.

TABLE IX.—COMPLETE RIVALRY—STEREOSCOPIC OBJECTS.

	R	OR	O	OY	Y	YG	G	GB	B	V	VP	P	
R.....	..	0	0	0	3	4	5	9	9	7	3	0	40
OR.....	0	..	0	0	0	3	2	9	10	8	4	0	36
O.....	0	0	..	0	0	0	2	3	7	6	2	0	20
OY.....	0	0	0	..	0	0	1	3	2	3	1	0	10
Y.....	3	0	0	0	..	0	0	1	1	1	1	0	7
YG.....	4	3	0	0	0	..	0	0	2	1	1	3	14
G.....	5	2	2	1	0	0	..	0	0	1	3	3	17
GB.....	9	9	3	3	1	0	0	..	0	0	0	1	26
B.....	9	10	7	2	1	2	0	0	..	0	0	2	33
V.....	7	8	6	3	1	1	1	0	0	..	0	1	28
VP.....	3	4	2	1	1	1	3	0	0	0	..	0	15
P.....	0	0	0	0	0	3	3	1	2	1	0	..	10
	40	36	20	10	7	14	17	26	33	28	15	10	256

TABLE X.—PARTIAL RIVALRY—STEREOSCOPIC OBJECTS.

	R	OR	O	OY	Y	YG	G	GB	B	V	VP	P	
R.....	..	0	0	0	1	10	11	7	5	4	6	0	44
OR.....	0	..	0	0	2	7	12	7	6	7	5	0	46
O.....	0	0	..	0	0	6	13	11	9	6	9	7	61
OY.....	0	0	0	..	0	2	9	12	14	8	12	9	66
Y.....	1	2	0	0	..	2	5	9	14	13	12	13	71
YG.....	10	7	6	2	2	..	0	5	11	11	15	13	82
G.....	11	12	13	9	5	0	..	1	2	6	10	12	81
GB.....	7	7	11	12	9	5	1	..	1	0	6	14	73
B.....	5	6	9	14	14	11	2	1	..	0	2	10	74
V.....	4	7	6	8	13	11	6	0	0	..	0	6	61
VP.....	6	5	9	12	12	15	10	6	2	0	..	0	77
P.....	0	0	7	9	13	13	12	14	10	6	0	..	84
	44	46	61	66	71	82	81	73	74	61	77	84	804

TABLE XI.—INCONSTANT MIXTURE—STEREOSCOPIC OBJECTS

	R	OR	O	OY	Y	YG	G	GB	B	V	VP	P	
R.....	..	0	1	3	5	2	0	0	2	4	5	0	22
OR.....	0	..	0	0	2	5	2	0	0	1	6	2	18
O.....	1	0	..	0	2	6	1	2	0	4	5	7	28
OY.....	3	0	0	..	0	7	6	0	0	5	3	6	30
Y.....	5	2	2	0	..	1	4	6	1	2	3	2	28
YG.....	2	5	6	7	1	..	2	7	3	3	0	0	36
G.....	0	2	1	6	4	2	..	2	7	7	3	1	35
GB.....	0	0	2	0	6	7	2	..	3	9	8	1	38
B.....	2	0	0	0	1	3	7	3	..	2	8	4	30
V.....	4	1	4	5	2	3	7	9	2	..	4	7	48
VP.....	5	6	5	3	3	0	3	8	8	4	..	5	50
P.....	0	2	7	6	2	0	1	1	4	7	5	..	35
	22	18	28	30	28	36	35	38	30	48	50	35	398

TABLE XII.—COMPLETE MIXTURE—STEREOSCOPIC OBJECTS.

	R	OR	O	OY	Y	YG	G	GB	B	V	VP	P	
R.....	..	16	15	13	7	0	0	0	0	1	2	16	70
OR.....	16	..	16	16	12	1	0	0	0	0	1	14	76
O.....	15	16	..	16	14	4	0	0	0	0	0	2	67
OY.....	13	16	16	..	16	13	7	0	0	0	0	1	70
Y.....	7	12	14	16	..	7	0	1	0	0	0	1	70
YG.....	0	1	4	7	13	..	14	4	0	1	0	0	44
G.....	0	0	0	0	7	14	..	13	7	2	0	0	43
GB.....	0	0	0	1	0	4	13	..	12	7	2	0	39
B.....	0	0	0	0	0	0	7	12	..	14	6	0	39
V.....	1	0	0	0	0	1	2	7	14	..	12	2	39
VP.....	2	1	0	0	0	0	0	2	6	12	..	11	34
P.....	16	14	2	1	1	0	0	0	0	2	11	..	47
	70	76	67	70	70	44	43	39	39	39	34	47	638

TABLE XIII.—SUMMARY—NO. OF CASES—STEREOSCOPIC OBJECTS.

	Complete Rivalry.	Partial Rivalry.	Inconstant Mixture.	Complete Mixture.	
R....	40	44	22	70	176
OR....	36	46	18	76	176
O.....	20	61	28	67	176
OY ..	10	66	30	70	176
Y.....	7	71	28	70	176
YG....	14	82	36	44	176
G.....	17	81	35	43	176
GB....	26	73	38	39	176
B.....	33	74	30	39	176
V.....	28	61	48	39	176
VP ...	15	77	50	34	176
P.....	10	84	35	47	176
	276	800	398	638	2112

TABLE XIV.—SUMMARY—NO. OF COLOURS—STEREOSCOPIC OBJECTS.

	Complete Rivalry	Partial Rivalry.	Inconstant Mixture.	Complete Mixture.
R.....	7	7	7	7
OR....	6	7	6	7
O.....	5	7	8	6
OY...	5	7	6	7
Y.....	5	9	10	7
YG....	6	10	9	7
G.....	7	10	10	5
GB....	6	10	8	6
B.....	7	10	8	4
V.....	8	8	11	7
VP....	7	9	10	6
P.....	5	8	9	7
	74	102	102	76

TABLE XV.—OBJECT, TRANSPARENT CRYSTAL ON CLEAR GLASS.

Result of Colour Combination.	STEREOSCOPIC EFFECT.			
	Perfect.	Impaired.	Slight.	None.
Complete Rivalry....	0	5	9	7
Partial Rivalry.....	24	46	14	5
Inconstant Mixture...	25	21	5	0
Complete Mixture....	102	1	0	0
	151	73	28	12

TABLE XVI.—OBJECT, OPAQUE CRYSTAL ON GROUND GLASS.

Result of Colour Combination.	STEREOSCOPIC EFFECT.			
	Perfect.	Impaired.	Slight.	None.
Complete Rivalry....	1	1	1	14
Partial Rivalry.....	21	26	6	52
Inconstant Mixture...	35	21	4	3
Complete Mixture....	79	0	0	0
	136	48	11	69

TABLE XVII.—OBJECT, PYRAMID ON CLEAR GLASS.

Result of Colour Combination.	Stereoscopic Effect.			
	Perfect.	Impaired.	Slight.	None.
Complete Rivalry....	27	2	2	1
Partial Rivalry.....	70	34	6	1
Inconstant Mixture...	39	2	0	0
Complete Mixture....	80	0	0	0
	216	38	8	2

TABLE XVIII.—OBJECT, PYRAMID ON GROUND GLASS.

Result of Colour Combination.	Stereoscopic Effect.			
	Perfect.	Impaired.	Slight.	None.
Complete Rivalry....	2	15	18	17
Partial Rivalry.....	11	50	18	19
Inconstant Mixture...	20	17	3	0
Complete Mixture....	74	0	0	0
	107	82	39	36

TABLE XIX.—SUMMARY OF XV.–XVIII.

Result of Colour Combination.	Stereoscopic Effect.			
	Perfect.	Impaired.	Slight.	None.
Complete Rivalry....	30	23	30	39
Partial Rivalry.....	126	156	44	77
Inconstant Mixture...	119	61	12	3
Complete Mixture.....	335	1	0	0
	610	241	86	119

Remarks on the tables in sections (1) *and* (2). The tables group the results in four divisions, according to the activity of the colours, i.e., the liveliness and persistency of the rivalry of the vision-fields, the two extremes being "complete rivalry," where the impressions in the respective eyes have qualitatively no influence upon each other, and "complete mixture," where there is an entire fusion of the two impressions.

The cases of complete rivalry for plane surfaces and stereoscopic figures respectively are shown in Tables III and IX. These are the only cases where there is absolutely no mixture effect, and their numbers are comparatively quite small. They are much less numerous than the cases of complete mixture, and are not a large proportion of the total. This phenomenon, as might be expected, was most frequent where the colours were nearly complementary (there was not any pair of exact complementaries), where also the cases of complete mixture were least frequent. The proportion of cases of complete rivalry was on the whole, slightly greater with stereoscopic objects than with surfaces.

The cases classified as "partial rivalry," and exhibited in Tables IV and X are very interesting. They show that even when there is most pronounced strife of the vision-fields, there is frequently at the same time a certain mixture effect. Either one or each of the competing colours is modified in the direction of the other, (e.g., red and green being the colours, the red appearing more orange-red and the green nearer to yellow) or else, especially where the colours are nearly complementary, one or both will appear paler than when seen alone, i.e., of less saturation. Comparison of these two tables shows a marked difference between the results with three-dimensional objects and those with plane surfaces. The proportion of cases of partial rivalry is decidedly larger with the former than with the latter.

Tables V and XI, "inconstant mixture," represent a variety of cases, ranging from those where there was a single colour, which, when regarded for a time, changed slightly toward one or the other of the competing colours and back again,

or toward each in turn, to those in which there was a decided strife of the vision-fields, but with a mixed colour appearing between the alternation of the competing colours. These phenomena, as will be seen from the numbers in these tables, are comparatively infrequent. There is a decided difference between the proportion of cases of partial mixture with three-dimensional objects and that with plane surfaces, the proportion being greater with the former.

Tables VI and XII show the cases of complete mixture of the colours. These cases are more numerous than might have been expected, in fact they form a very much larger proportion of the total number of combinations than do any of the others. Complete mixture of colours is not nearly as common with stereoscopic objects as with plane surfaces, showing that the effort required for the stereoscopic combination interferes decidedly with the complete mixing of the colours, though it has been shown, on the other hand, to produce a partial mixture effect more frequently than that occurs with plane surfaces.

Four tables of summaries are added, giving the totals of the preceding tables in parallel columns for convenience of comparison. Tables VII and XIII give the total numbers of cases of the occurrence of the respective phenomena. They show that the phenomenon which occurred most frequently with surfaces was that of complete mixture, with stereoscopic objects that of partial rivalry. With surfaces rivalry of modified colours was the next in order of frequency, and rivalry of unmodified colours in both cases much the least frequent of all. The proportion of cases of complete mixture is larger in Table VII than in Table XIII, but the cases of complete rivalry are also more numerous here. These results have been noticed already in connection with the preceding tables. These combined tables, however, furnish in addition a basis for comparison of the various colours with respect to the facility or difficulty with which they mix with other colours. Tables VIII and XIV summarize the results from a slightly different view. They show, not the number of times each phenomenon

occurs with each of the colours, but the number of other colours the combination of which with each of the colours results in the production of the respective phenomena. These four tables of summaries are illustrated graphically in Curves I to IV, in which the abscissa lines represent the twelve spectral intervals and the ordinates represent respectively the number of cases and the number of colours. The results as to numbers of colours and numbers of cases of occurrence correspond quite well. The spectral colours near the purple end are, on the whole, shown to be somewhat more active, i.e., to mix less readily, than those at the opposite end. The regions of greatest and of least mixture, however, are found between the middle and the ends. The colour which mixes most frequently and with the greatest number of other colours is the same in all the curves, namely, orange-yellow. From that point the curve goes somewhat regularly and sharply upward to blue, whence it abruptly declines.

Tables XV to XIX show the effect upon the stereoscopic combination of the differences in the colour of the impressions in the respective eyes. The results for each of the pairs of drawings used are given in a separate table, and the combined results in Table XIX. From these tables it appears that the combination is seldom much impaired where the colours are not too different to admit of even partial mixture. With rivalry of modified colours the stereoscopic effect was often completely preserved, and even in a number of cases with rivalry of pure colours. The cases in which there was no stereoscopic effect were comparatively few. (They occurred for the most part only where the competing colours succeeded each other very rapidly). They occurred also mainly, as the tables show, with the etchings upon ground glass, where also the complete mixture of colours was less common. This is no doubt to be explained by the fact that in these cases the colour contrast was stronger upon the lines than upon the surfaces.

A fact worthy of note is that with all the observers there appeared occasionally a lustre similar to that produced by

the combining of black and white objects or surfaces. With this there appeared also usually a "transparence" effect, one colour being reported as "seen through" the other. Careful examination of these cases showed them to be due to slight differences of brightness between the two colours. Re-adjustment of the lights always caused the lustre or transparence to disappear. These cases, however, suggest an interesting question regarding the problem of binocular lustre, as they seem to indicate that that phenomenon may be produced with much smaller differences of intensity between the two retinal impressions, where there is also a marked difference of quality.

(3) *Mixture of coloured and uncoloured impressions.* The apparatus and method employed in this series of experiments were the same as in the two preceding, and the objects were the same as in the last series, except that while one of the colours before described was behind the drawing presented to one eye, behind that presented to the other was one of a series of greys. Only one pair of the drawings described in section (2) were used, namely, those etched upon clear glass, and forming a transparent octahedral crystal (Fig. 3). Six greys of the Prang series were used, selected so as to be about equally graduated in brightness. In experimenting, the colour in use was made of equal intensity with the grey by adjusting the position of the lamps, in the same manner as before described for equalizing the intensity of the two colours in the experiments where different colours were presented to the respective eyes. The light illuminating the grey was passed through a gelatine which excluded any trace of yellow, leaving the light as nearly as possible absolutely colourless. Each of the six greys was combined with each of the twelve colours, the greys being kept on one side. Then the grey and the colour were interchanged, bringing the grey before the other eye, and the series repeated. Such a double series was made by one observer only, and by another a single series. There were thus in all three combinations of each of the six greys with each of the twelve colours. The total number of experi-

ments was therefore not nearly so great as in the investigation regarding the mixture of coloured and uncoloured impressions. The results, however, are of decided interest. They are in some respects more regular than with combinations of two colours, and exhibit other marked differences from the former results. The results of one series are given in full in Tables XX to XXV. The results of all three series are summarized in Tables XXVI to XXVIII. They are also graphically represented in Curves V to VII. Curve V combines the results in Tables XXVI and XXVII—the results for one observer. Curve VI represents the results for the other observer, and Curve VII gives the combined results of the two observers.

TABLE XX.—OBSERVER P. T. GREY NO. 1 IN LEFT EYE.

COLOUR IN RIGHT EYE.	EFFECT OF COMBINATION.
Red	Rivalry at first of light grey and brilliant red, then of grey and dull orange, finally mixing to orange of low saturation, but high intensity.
Orange-Red	Slight rivalry, subsiding almost immediately into light brown mixture.
Orange	Less rivalry. Unsteady brown mixture.
Orange-Yellow	Same effect as with orange, only lighter brown.
Yellow	Mixture, saturation growing less till yellow becomes very faint.
Yellow-Green	Rivalry at first, then yellowish mixture.
Green	Mixture, green gradually fading. Final effect good pea-green.
Green-Blue	No rivalry. Grey-green, fading to greenish grey.
Blue	At first rivalry of blue and grey, then mixture, with blue predominating at centre and grey at periphery.
Violet	Rivalry of bluish grey and pale violet in outer portions ; in centre, mixture, greyish violet.
Violet-Purple	Strong rivalry of greyish yellow and purple.
Purple	At first rivalry between light grey and purple of less saturation than when seen alone, finally settling into a faint yellow, with at times a suggestion of pink.

TABLE XXI.—OBSERVER, P.T. GREY NO. 2 IN LEFT EYE.

COLOUR IN RIGHT EYE.	EFFECT OF COMBINATION.
Red	Strong rivalry at first between red and grey, then less pronounced rivalry between red and orange-red.
Orange-Red	Slight rivalry of grey and orange, then mixture, orange with decided red spots. Finally settles into a brown.
Orange	Light brown. No rivalry.
Orange-Yellow	No rivalry. A light grey, with beautiful orange tinge in parts.
Yellow	Pale, slightly inconstant yellow.
Yellow-Green	Complete mixture, very slightly greenish grey.
Green	Complete mixture, light pea-green.
Green-Blue	Rivalry of grey and blue, settling down to a light grey with a tinge of blue.
Blue	Dark grey, with slight suggestion of blue at times.
Violet	Rivalry of violet and yellowish grey. Always some violet in places.
Violet-Purple	Rivalry of yellowish grey and purple. After a time grey lasts the longer.
Purple	Rivalry at first of light brown and purple, settling into an unsteady purplish brown.

TABLE XXII.—OBSERVER, P. T. GREY NO. 3 IN LEFT EYE.

COLOUR IN RIGHT EYE.	EFFECT OF COMBINATION.
Red	No rivalry. A light grey with slight pinkish tinge.
Orange-Red	No rivalry. Surface bright, with faint tinge of pink.
Orange	A faint pink, increasing in saturation. No rivalry;
Orange-Yellow	A pinkish white. No rivalry.
Yellow	No rivalry. Mixture appears like a dirty white.
Yellow-Green	Complete mixture, light green.
Green	A very light grey, with a suggestion of green.
Green blue	No rivalry. An agreeable light blue.
Blue	Light grey, with suggestion of blue.
Violet	Rivalry of violet and yellowish grey, the grey predominating.
Violet-Purple	Slight rivalry at first. Soon becomes a light grey, with suggestion of yellow. A portion of surface is covered with faint purple. Around periphery is dark blue.
Purple	Over a light brownish surface a slight and indefinite purple moves. Around periphery there is a bluish tinge.

TABLE XXIII.—OBSERVER P. T. GREY NO. 4 IN LEFT EYE.

COLOUR IN RIGHT EYE.	EFFECT OF COMBINATION.
Red	Rivalry of white with red which gradually becomes of less saturation.
Orange-Red	Faint orange. No rivalry.
Orange	Rivalry of white and pale red.
Orange-Yellow	Complete mixture, pinkish white.
Yellow	Mixture, very light brown.
Yellow-Green	Perfect mixture, light green.
Green	Perfect mixture, pale pea-green.
Green-Blue	Complete mixture, very light blue
Blue	Rivalry of white and very pale blue.
Violet	Continuous rivalry.
Violet-Purple	Rivalry. Grey appears white. Colour never covers whole surface, but is stronger around edges.
Purple	Continuous rivalry. The grey appears white.

TABLE XXIV.—OBSERVER, P.T. GREY NO. 5 IN LEFT EYE.

COLOUR IN RIGHT EYE.	EFFECT OF COMBINATION.
Red	Strong rivalry of red with white.
Orange-Red	Rivalry of white and dark brown, brown becoming fainter at each re-appearance.
Orange	No rivalry. Effect is yellowish grey.
Orange-Yellow	A distinct yellow. No rivalry.
Yellow	No rivalry. Very faint yellow.
Yellow-Green	Light green. No rivalry.
Green	No rivalry. Effect is pea-green.
Green-Blue	Mixture, varying from pale to very decided green. Centre is more green than periphery.
Blue	Inconstant mixture, varying from bluish-white to light blue.
Violet	Strong rivalry of white and violet ; violet never covers whole surface.
Violet-Purple	Rivalry ; grey seems white. Purple is dark, but only comes over half the surface.
Purple	Rivalry ; first white, then purple, which on disappearing leaves a yellowish tinge, then purple comes again, but disappears quickly.

TABLE XXV.—OBSERVER, P.T. GREY NO. 6 IN LEFT EYE.

COLOUR IN RIGHT EYE.	EFFECT OF COMBINATION.
Red	Rivalry of red and white.
Orange-Red	Rivalry of white and brownish red, the white predominating.
Orange	Rivalry, changes not very rapid. The appearance is alternately white and dark brownish.
Orange-Yellow	Rivalry of white and a brownish hue.
Yellow	Rivalry of light grey and very light brown, brown growing weaker.
Yellow-Green	Indefinite greyish effect, which passes into a white. No rivalry.
Green	No rivalry. A uniform pale pea-green.
Green-Blue	First white, then green, which remains, but grows less saturated.
Blue	Rivalry of white and blue, which settles into a white, with a strong tinge of blue.
Violet	Rivalry of white and violet. Some colour always remains around edges.
Violet-Purple	Strife between white and purple, white greatly predominating.
Purple	Rivalry ; grey at first appears white, later yellow. Purple appears first as a faint red, later as a decided purple.

TABLE XXVI.

OBSERVER, P.T. GREY BEFORE LEFT EYE, COLOUR BEFORE RIGHT EYE.

	RED.						ORANGE-RED.						ORANGE.						ORANGE.-YELLOW.					
	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6
Permanent Rivalry		*		*	*	*					*	*				*		*						*
Rivalry Gradually Ceasing	*							*																
Rivalry Quickly Ceasing							*						*						*					
Inconstant Mixture																								
Perfect Mixture			*						*	*				*	*	*				*	*	*	*	

	YELLOW.						YELLOW-GREEN.						GREEN.						GREEN-BLUE.					
	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6
Permanent Rivalry						*																		
Rivalry Gradually Ceasing																								
Rivalry Quickly Ceasing							*													*				*
Inconstant Mixture		*																					*	
Perfect Mixture	*		*	*	*			*	*	*	*	*	*	*	*	*	*	*	*		*	*		

	BLUE.						VIOLET.						VIOLET-PURPLE.						PURPLE.					
	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6
Permanent Rivalry				*			*	*	*	*	*	*	*	*		*	*	*			*	*	*	*
Rivalry Gradually Ceasing						*													*	*				
Rivalry Quickly Ceasing	*														*									
Inconstant Mixture		*			*																			
Perfect Mixture			*																					

TABLE XXVII.

OBSERVER, P. T. GREY BEFORE RIGHT EYE, COLOUR BEFORE LEFT EYE.

	RED.						ORANGE-RED.						ORANGE.						ORANGE-YELLOW					
	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6
Permanent Rivalry.....	*	*	*	*	*	*	*	*	*	*	*		*			*	*	*	*	*			*	
Rivalry Gradually Ceasing.....												*		*							*	*		*
Rivalry Quickly Ceasing.....																								
Inconstant Mixture.....															*									
Perfect Mixture.....																								

	YELLOW.						YELLOW-GREEN.						GREEN.						GREEN-BLUE.					
	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6
Permanent Rivalry.....						*											*				*		*	
Rivalry Gradually Ceasing.....																								*
Rivalry Quickly Ceasing.....		*											*	*	*	*		*		*		*		
Inconstant Mixture.....								*																
Perfect Mixture.....	*		*	*	*		*		*	*	*	*							*					

	BLUE.						VIOLET.						VIOLET-PURPLE.						PURPLE.					
	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6
Permanent Rivalry.....			*	*	*	*	*		*	*	*	*	*	*		*	*	*	*		*	*	*	*
Rivalry Gradually Ceasing.....	*	*						*												*				
Rivalry Quickly Ceasing.....																								

TABLE XXVIII.—OBSERVER, J. M.

	Red.						Orange-Red.						Orange.						Orange-Yellow.					
	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6
Permanent Rivalry	*	*	*	*		*		*	*	*		*												
Rivalry Gradually Ceasing					*									*	*									
Rivalry Quickly Ceasing											*													
Inconstant Mixture																		*						*
Perfect Mixture							*						*			*	*		*	*	*	*	*	

	Yellow.						Yellow-Green.						Green.						Green-Blue.					
	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6
Permanent Rivalry																								
Rivalry Gradually Ceasing																					*			
Rivalry Quickly Ceasing			*																					
Inconstant Mixture															*									
Perfect Mixture	*	*		*	*	*	*	*	*	*	*	*	*	*		*	*	*	*	*		*	*	*

	Blue.						Violet.						Violet-Purple.						Purple.					
	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6
Permanent Rivalry		*		*				*	*	*	*	*		*	*	*	*	*	*	*	*	*	*	*
Rivalry Gradually Ceasing							*																	
Rivalry Quickly Ceasing																								
Inconstant Mixture			*		*	*																		
Perfect Mxiture	*												*											

Results : 1. The character of the rivalry of the vision-fields differed in some important respects from that which occurred with two colours. (a) There were no cases of "complete rivalry," i.e., of rivalry of sensations of quite the same character as those in monocular vision. Either the grey was brighter or had some tinge of colour, or the colour was of less saturation or changed in tone, or several or all of these modifications occurred together. (b) Orange-red, orange, and orange-yellow very frequently, and even yellow and purple in some cases, became brown or brownish. This never occurred with red, which when modified appeared less bright, or of lower saturation (i.e., pinkish) or changed to orange-red or orange. It was noticeable that the brown effect came not less frequently with the brighter than with the darker greys. (c) The rivalry, even when very pronounced at first, very frequently subsided more or less quickly into an inconstant, or even a perfect mixture. (d) The phenomena are accordingly classified in the tables in this section upon a different basis from that adopted in the two preceding sections. Instead of the completeness of the rivalry, i.e., the absence of any modification of the competing colours, the criterion is its permanence, or the rapidity with which it subsides. The term "inconstant mixture" has also a slightly different significance from that attached to it in the former tables. There it was extended to include the cases where there was rivalry, sometimes even quite pronounced, but with a mixed colour appearing between the alternating colours. In the present tables it is used only for cases where there was no rivalry, beyond an unsteadiness of the mixed colour.

2. Complete mixture of the impressions was less common than with two colours. This was, of course, to be expected, as in many cases the two colours were much more alike than a coloured and an uncoloured impression.

3. Comparison of the various colours as to the facility with which they mix binocularly with uncoloured light shows that their relative quiescence is not quite the same when they are combined with uncoloured light as when they are combined

with one another. The regions of most strenuous rivalry, as will be seen by a glance at Curves V to VII, are at the very ends of the spectrum, and the region where most mixture occurs is about at the middle, the gradation between these extremes being on the whole quite regular. The colour with which most mixture occurred is in each of the curves shown to be yellow-green. Here the rivalry of the fields was scarcely ever very pronounced, and usually did not occur at all. With violet, violet-purple, and purple, which appear at or near the maximum, the rivalry was not, perhaps, so much more marked than with some other colours, but it was more persistent. The impression did not settle into any one colour so frequently as with other combinations.

4. The greys which mixed best were those of medium brightness. This was the case in spite of the fact that the intensities of the grey and the colour used in each experiment were always carefully equalized by the adjustment of the lamps.

5. The colours mostly tended to become fainter when regarded for a time. In some cases, however, they persisted, and in a few instances they even became more pronounced after a time than at first.

6. In a number of cases with violet, violet-purple and purple the competing grey had a yellow tinge. This occurred both with the deeper and the lighter greys. As, according to the results of Miss Baker,[1] who used the same colours, violet and yellow-green are about complementary, these are probably to be regarded as cases of binocular contrast.

7. The stereoscopic effect was found to be practically completely preserved in almost every case. The exceptions occurred near the beginning of the experiments when the eyes of the observer, being unused to the conditions, were probably more easily fatigued. When these experiments were repeated later it was found that in every case the stereoscopic effect was complete.

(4) *Mixture of colours covering the entire vision-field.* The experiments so far reported were all made with surfaces or

[1] University of Toronto Studies, Psychological Series, Vol. ii, No. 1, p. 16.

objects covering only a portion of the vision-field, the remainder being darkened. The following experiments were differently arranged, the colours covering the whole of the field of vision, so that not only were the colours more extended spacially, but also the possibility of comparison was lessened. The apparatus consisted simply of a large pair of goggles similar to those worn by automobilists, but with removable glasses. The frames of the goggles were fitted with grooves, closed at the bottom, but left open at the top, into which square glass slides could be easily inserted. The goggles were fitted closely to the face by means of some light fur attached to the back of the frames, so that they could be adjusted with comfort to the observer, and yet exclude all light. They were held snugly in place by an elastic band which went round the head. Two sets of coloured glass slides were used. One was of mineral-dyed glasses, five in number, the colours being red, yellow, green, blue and violet. The other set was composed of coloured gelatine combinations placed between thin sheets of plain glass. These were twelve in number, and divided the entire spectrum into approximately equal sections. Slides of uncoloured plate glass were also used. The spectroscopical analysis of the colours used is as follows :

SPECTROSCOPICAL ANALYSIS OF THE COLOURS USED.
I.—GELATINE COLOURS.

Colour.	Undiminished in Intensity.	Somewhat Weaker.	Very Weak.
Red (1).....	720—589	.....	500—410
Orange (2).....	720—580	560—530	580—560 470—440
Orange-Yellow (3)..	720—520	520—510	
Yellow (4).....	720—500	510—480	480—455
Yellow-Green (5)...	580—490	650—580 490—440	
Green (6).....	580—465	730—680 610—580 465—450	730—680 450—435
Green-Blue (7).....	570—440	440—425 590—570	730—680
Blue-Green (8).....	540—440	570—540 440—430	730—690
Blue (9).....	530—425	560—530	425—410 720—665
Violet (10).....	470—V.end 720—650	500—470	
Violet-Purple (11)..	510—V.end 710—620	620—590 530—510	
Purple (12).....	720—590	480—V. end	590—480

II.—MINERAL COLOURS.

Colour.	Undiminished in Intensity.	Somewhat Weaker.	Very Weak.
Red	720—610	610—590	
Yellow	710—550	550—490	490—460
Green	600—500	630—600 500—460	460—440
Blue	570—550 490—end	640—600 550—490	720—640 660—570
Violet		720—530 450—V.end	530—450

In experimenting, the goggles, without any glasses in, were first adjusted over the observer's eyes. He then closed his eyes, and a pair of differently coloured glasses were slipped into place by the experimenter. The observer was then told to open his eyes, being careful to open both at once, and not at any time to close one eye alone. Observations were then made regarding the colour of objects both within and without the room. In observing objects outside, care had to be exercised to seat the observer before the window so that there should be no interference from the bars of the window sash. If the vertical centre bar of the sash came in the middle of the field it was found that the colours on the two sides were more readily distinguished. The observer was seated at the window at the beginning of the experiments, and looking out reported the appearance of everything in the vision-field generally, i.e., whether darker or brighter than ordinary, or whether there was any definite prevailing colour tone. He then reported the appearance of prominent objects in the landscape, such as the sky, trees, a bright yellow house with dark green shutters, a red brick outhouse, snow and grass, grey brick and stonework of the University buildings, a slate roof just outside the window. After this some observation was made of objects within the room. Then the observer was handed two large cards, one black and one white, on each of which were arranged in a circle twenty small discs of coloured paper, mostly of the Milton-Bradley series, of approximately equal spectral differences, and he was asked to give his judgment of several of the colours. Then he was asked to raise

his eyes and tell, as nearly as he was able, what colours were before his eyes. Finally the observer closed his eyes, the goggles were removed and he was then directed to open his eyes, to look with crossed eyes, and to report what after-effect, if any, he saw. Two complete series of experiments were made with the gelatine colours, each for a different observer. In each series one constant colour was employed, with which each of the others was in turn combined. The series, however, was not carried on uninterruptedly, but other combinations were interspersed, so that the observer was not only ignorant of the actual colours of the glasses at any time before his eyes, but was not even aware of any constant colour being used. A series was also made with combinations of mineral-dyed and plain glasses, which was not, however, arranged in any definite order. The results of the three series are given fully in Tables XXIX to XXXI.

Three other observers also made series of experiments, using the six mineral-dyed glasses only. The results of these are not given *in extenso*, as their general character is similar to the results obtained by the former observers. None of the results lend themselves very readily to tabulation in more condensed form, owing to the irregularity of the effects of the combinations of colours upon the colour of objects in the vision-field. The appended summary of results, however, is based upon the reports of the five observers.

TABLE XXIX.—BLUE-GREEN (No. 8) BEFORE RIGHT EYE.

Colour Before Left Eye.	Subject of Report.	RESULTS.
Red (No. 1)	Colour of Surrounding Objects.	Everything looked red and brighter than normally. Red brick wall appeared brighter red. The hands had a suggestion of yellow over them There was no rivalry of the vision fields.
	Colours on Card.	No good green seen at all. No. 15 (a dark blue) is the only good blue.
	Colour of Glasses.	Cannot tell what colours.
	After-Effect With Crossed Eyes.	From right eye red, from left greenish.

TABLE XXIX—(CONTINUED).

Colour Before Left Eye.	Subject of Report.	RESULTS.
Orange (No. 2)	Colour of Surrounding Objects.	Everything appeared a little darker.
	Colours on Card.	No good green or blue. Nos. 2 and 3 (dark and light red) had lustre.
	Colour of Glasses.	Yellow on right side and blue on left.
	After-Effect With Crossed Eyes.	From right eye bluish, from left eye no colour.
Orange-Yellow (No 3)	Colour of Surrounding Objects.	(This experiment was performed on a dark day.) Everything much darker. Yellow painted house had lost its yellow colour. Slight rivalry between yellow-green and violet. Snow had a yellow-green tinge. Trees and stone sills of buildings were tinged with violet, dingy white brick appeared purplish.
	Colours on Card.	No good blue. Nos. 1, 2, 3, 4 and 5 had lustre. 18 and 19 (violet and violet-purple) were brown with slight suggestion of violet.
	Colour of Glasses.	Could not tell at end of experiment, but from memory of first impressions judged violet on left and yellow-green on right.
	After-Effect With Crossed Eyes.	From right eye blue, from left no colour.
Yellow (No. 4)	Colour of Surrounding Objects.	Red brick building looked redder than it was remembered. Sky was blue-green. Yellow house was a mixture of yellow and pink. Hands and face of experimenter looked ghastly, with violet tinge around edges. Everything a little darker.
	Colours on Card.	No red. Red and orange discs appeared chocolate. 6 and 7 (orange-yellow and yellow-orange) were good browns. 17, 18 and 19 (blue-violet, violet, and violet-purple) were dark grey with a tinge of violet.
	Colour of Glasses.	Blue on right, green on left.
	After-Effect With Crossed Eyes.	From right eye blue, from left no colour.

TABLE XXIX—(CONTINUED).

Colour Before Left Eye.	Subject of Report.	RESULTS.
Yellow-Green (No. 5)	Colour of Surrounding Objects.	Everything a little darker. Yellow house appeared dirty yellow with a little green. Sky bluish-green. Face pallid, lips almost colourless. Not the least rivalry.
	Colours on Card.	No red. Red and orange appeared dark brown or chocolate. No. 14 (blue-green) appeared bluish-grey.
	Colour of Glasses.	Bluish on right, green on left.
	After-Effect With Crossed Eyes.	From right eye purplish, from left eye brownish.
Green (No. 6)	Colour of Surrounding Objects.	(No sun shining). Everything dark. Snow greenish. Yellow house appeared dirty yellow with a little green. Sky bluish-green. Face pallid, lips almost colourless. Not the least rivalry.
	Colours on Card.	No red. Reds were brown or chocolate.
	Colour of Glasses.	Could not tell at all..
	After-Effect With Crossed Eyes.	From right eye purple, from left no colour.
Green-Blue (No. 7)	Colour of Surrounding Ojects.	Everything darker. Red brick wall greyish. Snow darker than usual. Sky had leaden appearance. Hand looked darker than usual with greenish lustre around edge.
	Colours on Card.	No red. Reds were dark brown. No. 13 (very greenish-blue) almost colourless.
	Colour of Glasses.	Blue, but could not distinguish sides.
Blue (No. 9)	Colour of Surrounding Objects.	Yellow house looked pink. White and red brick both appeared red. Snow and sky looked blue. Face pallid, and no colour in lips at all.
	Colours on Card.	Nos. 2-5 dark reddish-brown. No yellow on card. 6 and 7 (orange-yellow and yellow-orange) were dark brown. No. 9 (green-yellow) was pink. 8 and 10 (yellow and yellow-green) were dark brown. 11 and 12 (green) were dark grey.
	Colour of Glasses.	Blue on right. Could not tell what colour on left.
	After-Effect With Crossed Eyes.	From right eye green, from left no colour.

TABLE XXIX—(CONTINUED).

Colour Before Left Eye.	Subject of Report.	RESULTS.
Violet (No. 10)	Colour of Surrounding Objects.	Everything very dark. Red brick wall fiery red. Sky dark blue. Yellow wall had pinkish tinge. Hands were purplish.
	Colours on Card.	6, 7 and 8 (orange-yellow and yellow) varied between red and yellow. 2, 3 and 5 (red and orange) were very brilliant reds. 4 (orange-red) was a beautiful pink.
	Colour of Glasses.	Blue on left, on right could not tell.
	After-Effect With Crossed Eyes.	From right eye greenish, from left eye red.
Violet-Purple (No. 11)	Colour of Surrounding Objects.	Everything had purple tinge, and was much darker. Snow was bluish, hands reddish.
	Colours on Card.	No good red, yellow or blue.
	Colour of Glasses.	Left, blue or violet ; right, could not tell.
	After-Effect With Crossed Eyes.	From right eye faint red, from left eye green.
Purple (No. 12)	Colour of Surrounding Objects.	Shadows from trees and buildings were purple-violet. Everything darker. Sky pink and blue. Yellow house appeared as without glasses. Red brick wall had some yellow in it.
	Colours on Card.	Green entirely absent. Nos. 2 and 4 had slight lustre. No. 9 (green-yellow) appeared white. No. 13 (green-blue) appeared grey with a suggestion of blue.
	Colour of Glasses.	Blue on right, purple on left.
	After-Effect With Crossed Eyes.	From right eye green, from left eye brown.

TABLE XXX.—YELLOW-GREEN (No. 5) BEFORE LEFT EYE.

Colour Before Right Eye	Subject of Report.	RESULTS.
Red (No. 1)	Colour of Surrounding Objects.	Whole vision field darker. Slight rivalry of green and pink, but green soon entirely disappeared. Dark yellow or brown leaves appeared bright yellow. Yellow house brighter. Green lines of note-book were purple. Sky had a purplish tinge, and darker than usual.
	Colours on Card.	Yellows less saturated. Most of the colours purplish.
	Colour of Glasses.	On right, purple, on left, could not tell, but thought yellow.
	After Effect With Crossed Eyes.	From right eye faint red, from left, green.
Orange (No. 2)	Colour of Surrounding Objects.	Everything darker. Some rivalry at first. Later, colours blended, and appeared something between red and purple. Yellow house was lighter yellow.
	Colours on Card.	18, 19, and 20 (violet, violet-purple and purple) had nearly lost their violet or purple tone, and were of a dingy hue. No. 6 (orange-yellow) was between brown and dark yellow.
	Colour of Glasses.	On right violet, on left could not say.
	After-Effect With Crossed Eyes.	From right eye violet, from left no colour.
Orange Yellow (No. 3)	Colour of Surrounding Objects.	(Sun shining brightly). Everything has a yellow tint. Slight rivalry at first, but soon ceased. Green fir-tree dark green, but more yellow-green where sun shines on it. Red brick wall appeared dull reddish-brown.
	Colours on Card.	Greens nearer yellow. Blues more purplish.
	Colour of Glasses.	Slight yellow tinge. Could not distinguish between the two sides.
	After-Effect.	None from either eye.
Yellow (No. 4)	Colour of Surrounding Objects.	Everything had bright yellow tint. Yellow house as usual. No rivalry.
	Colours on Card.	Greens more bluish. Nos. 2 and 3 had slight lustre.
	Colour of Glasses.	Both eyes had yellow glasses.

TABLE XXX—(CONTINUED)

Colour Before Right Eye.	Subject of Report.	RESULTS,
Green (No. 6)	Colour of Surrounding Objects.	Sky dark blue. Hand pallid.
	Colours on Cards.	Red and orange appeared brownish. Two cards, one black, the other white, with the same colours on, being shown, the colours were observed to show up better on the dark card.
	Colour of Glasses.	On the right side light blue, on left, yellow.
	After-Effect	From right side a slight pink, from left side yellow.
Green-Blue (No. 7)	Colour of Surrounding Objects.	(Experiment performed in bright sunshine.) Everything tinged with yellow-green, and seems dull. Yellow house appears as usual. Cannot distinguish red bricks of the barn as red.
	Colours on Card.	Discrimination much the same as without glasses.
	Colour of Glasses.	Could not say decidedly, but had a vague impression of green.
	After-Effect.	No after-effect.
Blue Green (No. 8)	Colour of Surrounding Objects.	Everything much darker, and had a slight yellow tinge. Yellow house was quite yellow. Snow where sun shining on it was bluish.
	Colours on Card.	Reds appeared dark brown, so dark as to be almost without colour.
	Colour of Glasses.	Blue on right, yellow on left.
	After-Effect.	From left eye violet. No after-effect from right eye.
Blue (No. 9)	Colour of Surrounding Objects.	At first slight rivalry between blue and green, which soon ceased. Snow and yellow building had normal appearance. Sky appeared dark blue. (It was really light blue-grey.) Hand had a pallid appearance.
	Colours on Card.	No. 2 appeared dark brown. No. 1 dark dirty brown. No good red. 11 and 12 (green) were blue-green.
	Colour of Glasses.	Could not tell what colours he had on his eyes, but there seemed a tinge of blue over the vision-field.
	After-Effect.	No after-effect.

TABLE XXX—CONTINUED.

Colour Before Right Eye	Subject of Report.	RESULTS.
Violet (No. 10)	Colour of Surrounding Objects.	Everything had a hazy appearance with a little violet tinge. Yellow leaves seemed very bright yellow. Yellow house had a slight tinge of green. Hands looked a little darker than usual. Occasionally, looking past the edge of any object, e.g., chimney, there appeared a purplish tinge approaching red. The violet tinge to everything disappeared and again re-appeared. On its re-appearance, the hands had a distinct purple tinge, and experimenter's lips were slightly blue.
	Colours on Card.	No. 12 (green) was yellow with slight greenish tendency. No. 17 (blue-violet) was "dark blue."
	Colour of Glasses.	On right, light blue, on left could not tell.
	After-Effect.	Violet from left eye, no effect from right eye.
Purple. (No. 12)	Colour of Surrounding Objects.	(Experiment performed on a dull day.) A purplish tinge over everything, gradually growing lighter: right side a little darker than left. Dark yellow leaves appeared bright yellow. Face looked death-like, lips as though almost bloodless.
	Colours on Card.	No. 1 appeared bronze or brownish-orange. No. 10 (yellow-green) was a pale yellow. No. 12 (green) was yellowish-blue. Slight lustre from Nos. 2 and 3.
	Colour of Glasses.	On right, light pink, on left, very light pink.
	After-Effect.	No after-effect.

TABLE XXXI.

Colour. Right Eye.	Colour. Left Eye.	Subject of Report.	RESULTS.
Mineral Violet.	Mineral Blue.	Colour of Surrounding Objects.	The whole vision-field had a purplish tinge, and the light was dimmer. Grass where sun shone on it was more yellowish than usual. The evergreen tree was almost black. The relation of white and yellow in the yellow house (cornice, etc., white) was about normal, the colour being darker than remembered. Sky appeared purplish, the colour being more prominent on suddenly turning to look up at it. Hands had an unnatural appearance, hardly describable.
		Colour of Glasses.	Cannot tell anything about colour of glasses.
		After-Effect.	Very bright, but no after-image.
Mineral Red	Mineral Yellow.	Colour of Surrounding Objects.	Sky seemed a brownish-red, getting darker. Yellow leaves seemed dark brown in centre.
		Colours on Card.	No. 20 (purple) was purplish-red. 11 (green) was normal.
		Colour of Glasses.	On right a shade of red, on left, green.
		After-Effect.	Indefinite impression of colour, quickly disappearing. No distinction between the sides.
Purple Gelatine (No. 12)	Yellow-Green Gelatine (No. 5)	Colour of Surrounding Objects.	This experiment was performed on a dark day. There was a pinkish tinge gradually growing lighter, the right eye being a little darker than the other. The dark yellow leaves appear light yellow. The experimenter's face appeared corpse-like, the lips bloodless.
		Colours on Card.	Nos. 2 and 3 had lustre.
		Colour of Glasses.	On right eye light pink, on left, very light pink.
		After-Effect.	Only effect is that on removing glasses everything is brighter.
Mineral Green	Uncoloured Glass	Colour of Surrounding Objects.	This experiment was performed on a dull day. On opening the eyes the right eye seemed to have a shade of yellow, the left having a very slight tinge of the same colour. The effect on the right eye seemed to be growing weaker.

TABLE XXXI.—CONTINUED.

Colour. Right Eye.	Colour. Left Eye.	Subject of Report.	RESULTS.
Mineral Green.	Uncoloured Glass.	Colour of Glasses.	In right eye light yellow, in left very indefinite, and could not tell what colour ,if any.
		After-Effect.	After removing glasses and blinking, very faint tinge of purple (negative after-image).
Mineral Blue	Mineral Yellow.	Colour of Surrounding Objects.	On opening the eyes the vision-field seemed somewhat darkened. Rivalry of yellow and blue followed.
		Colours on Card.	No. 13 (green-blue) was a pale blue, but with no green in it. No. 13 (a green near to yellow) was quite yellow.
		Colour of Glasses.	On right violet or blue, on left, cannot tell.
Gelatine Orange (No. 2)	Mineral Green.	Colour of Surrounding Objects.	Everything appeared brighter, with pink shade. The yellow house is rather a dark yellow. The colour of the (green) shutters could not be determined. The experimenter's face had a bluish tinge, as if cold.
		Colours on Card.	Reds had lustre effect. No. 10 (yellow-green) was "light green." No. 13 (green-blue) was a greyish blue.
		Colour of Glasses.	On right eye blue, on left, green.

Summary of Results. 1. Competition or rivalry of th vision-fields is never prominent. In some cases, on first open ing the eyes there was a slight struggle of the impressions but this soon ceased, and after a few moments the competitio was no longer observable. The observer was frequentl unable to distinguish between the colours of the two glasses even when attending exclusively to this point.

2. The result of the mixture of the two impressions wa not usually, as with the former method of binocular mixture to produce a colour midway between the two that were com bined. Sometimes the total impression would be quite nea

to the quality of one or other of the monocular colours, but even when it was quite unlike either of them the result was not always that produced by other methods of mixing.

3. The colour quality of the impression was usually very vague. Coloured objects in the field of vision were noticed to have a different appearance from that remembered, but the attempt to tell what was the colour of the glasses before the eyes was seldom successful. Often it was only concerning one side that the observer could give a decided opinion. Seldom did his judgment correspond to the objective facts. Sometimes he would be right as to one of the colours, but wrong as to the other. And even when approximately correct as to the colours of both glasses, he would often be mistaken regarding the eyes before which the respective colours were presented.

4. The rather frequent appearance of a lustre effect is noteworthy. This phenomenon appeared only upon red or orange-coloured surfaces (except once or twice with purple) of small area. It was mostly upon the small coloured discs on the card that it was noticed. It was, however, quite plainly seen upon the very small, bright red leaves of ivy, growing round a stone chimney just outside the window.

III. STEREOSCOPIC LUSTRE FROM DIFFERENCE OF INTENSITY AND OF COLOUR BETWEEN THE RETINAL IMAGES.

In the previous article, dealing with the intensity relations of stereoscopic vision[1] there were described some experiments upon the production of lustre by differences of brightness between the images in the two eyes. A further problem in that connection was suggested by the results of the experiments in binocular mixture of colours, reported in a preceding section of the present article. As mentioned there, there occurred quite frequently a lustre effect, which, upon closer examination, appeared to be due to differences of intensity so slight as to have otherwise passed unnoticed. In the

[1] University of Toronto Studies, Psych. Series, Vol. ii, No. 2.

experiments upon stereoscopic lustre with uncoloured light, such very slight differences of brightness had not been found to produce the phenomenon, so that it seemed probable that the effect would appear with smaller differences of brightness where there is also a decided difference of colour. This question was investigated by a method similar to that employed in the experiments with white light, the only difference being that on the rear wall of the apparatus, in place of the squares of white paper and black velvet respectively, there were placed squares of differently coloured paper. The objects were, as before, etchings on plate glass (Fig. 4). The two pairs used both formed truncated pyramids with the apices toward the observer. Seven colours were used, chiefly of the Milton-Bradley series, viz., red, orange, yellow, green, blue, violet, and purple. These were illuminated by an 8 c.p. incandescent electric lamp on eachside of the apparatus. The colours obtained by this arrange-ment were of course by no means spectrally pure, but they possessed the additional interest of being more like the colours commonly seen. The spectra reflected by the papers under the prevailing conditions of illumination, and their comparative intensities, were as follows :—

Name of Colour.	Comparative Intensity.	Portion of Spectrum Visible in $\mu\mu$
Red.....	360	680–480 (640)
Orange.....	360	670–550 (590–600)
Yellow.....	310	670–500 (570)
Green.....	320	650–500 (530–540)
Blue.....	125	Whole spectrum dimly visible (500).
Violet.....	180	Whole spectrum visible—yellow and yellow-green very weak.
Purple.....	180	Whole spectrum visible—yellow and green weak.

One colour being placed opposite the inner lens of the stereoscope, i.e., the one before which the episkotister disc revolved, and a different one opposite the other lens, the disc was then adjusted to admit only a single degree of light, and the amount gradually increased to the largest amount that

the disc was capable of admitting, viz. 320°, at which point no difference could be noticed between the effect and that of the full light. Then the colour on the unobscured side was replaced by another, and so on until all of the other six colours had been combined with the partially obscured one. Then another colour was placed behind the disc, and each of the others combined with it, as before. By this means each of the seven colours, in all degrees of brightness, was combined with each of the others. The results are summarized in Tables XXXII to XLV, which show also the amounts of light which had to be admitted through the disc for the production of any, and of complete stereoscopic combination. With regard to lustre also, the figures indicate the smallest opening of the disc with which it appears at all, and the least opening with which it is complete. Wherever the lustre was reported as "decided" or "perfect" it continued so, as the opening of the disc widened, even up to 360°. The colour named in the heading of the table is in each case the colour before which the episkotister was rotated; the colours indicated in the first column of the tables are those combined with it.

Two series were also made in the same way, combining white with coloured light. In one of these the white was behind the episkotister, and the colour remained constant in intensity, in the other the white was constant and the colours behind the disc. The results are shown in Tables XLVI–XLVII.

TABLE XXXII.—RED. OBSERVER, W.A.M.

Compared Colour.	Opening of the Episkotister Disc.	Ratio of the intensities of the objects presented to the respective Eyes.	Lustre.	Stereoscopic Effect.
Orange.	10°	36.00	None.	Partial.
	20°	18.00	Slight.	Do.
	40°	9.00	Brighter.	Good.
	60°	6.00	Good.	Do.
Yellow.	30°	10.33	None.	Imperfect.
	60°	5.16	Slight.	Good.
	100°	3.10	Decided.	Do.
Green.	8°	40.00	None.	Partial.
	10°	32.00	None.	Complete.
	60°	5.33	Slight.	Do.
	100°	3.20	Perfect	Do.
Blue.	10°	12.50	None occurs.	Partial.
	20°	6.25		Good.
Violet	10°	18.00	None occurs.	Partial
	30°	6.00		Good.
Purple	10°	18.00	None. occurs.	Partial.
	40°	4.50		Good.

TABLE XXXIII.—ORANGE. OBSERVER, W.A.M.

Compared Colour.	Opening of the Episkotister Disc.	Ratio of the intensities of the objects presented to the respective Eyes.	Lustre.	Stereoscopic Effect.
Red.	6°	60.00	None.	Poor.
	12°	30.00	Do.	Distinct.
	40°	9.00	Slight.	Do.
	160°	2.25	Distinct.	Do.
Yellow.	8°	38.75	None occurs.	With effort.
	20°	15.50		Good
Green.	10°	32.00	None occurs.	With effort.
	20°	16.00		With ease.
Blue.	8°	15.62	None.	Partial.
	50°	2.50	Do.	Good.
	60°	2.08	Slight.	Do.
	90°	1.38	Decided.	Do.
Violet	10°	18.00	None.	Poor.
	30°	6.00	Do.	Good.
	70°	2.57	Faint.	Do.
	120°	1.50	Uncertain.	Do.
Purple.	10°	18.00	None.	Partial.
	30°	6.00	Do.	Complete
	70°	2.57	Slight.	Do.
	100°	1.80	Decided.	Do.

TABLE XXXIV.—YELLOW. OBSERVER, W.A.M.

Compared Colour.	Opening of the Episkotister Disc.	Ratio of the intensities of the objects presented to the respective Eyes.	Lustre.	Stereoscopic Effect
Red.	10°	41.80	None.	Partial.
	15°	24.64	Slight.	Do.
	30°	13.93	Better.	Good.
	40°	10.45	Good.	Do.
Orange.	10°	41.80	None occurs.	Partial.
	30°	13.93		Good.
Green.	10°	37.16	Slight.	None.
	30°	12.38	Good.	Partial. (Never become perfect)
Blue.	6°	24.19	None.	Poor.
	15°	9.67	Do.	Good.
	60°	2.41	Slight.	Do.
	90°	1.61	Decided.	Do.
Violet	8°	25.80	None occurs.	Partial.
	15°	13.93		Good.
Purple	6°	34.83	None.	Partial.
	15°	13.93	Do.	Do.
	70°	3.15	Slight.	Perfect.
	90°	2.03	Good.	Do.

TABLE XXXV.—GREEN. OBSERVER, W.A.M.

Compared Colour.	Opening of the Episkotister Disc.	Ratio of the intensities of the objects presented to the respective Eyes.	Lustre.	Stereoscopic Effect.
Red.	10°	39.75	None.	Partial.
	20°	19.87	Do.	Complete.
	60°	6.65	Slight.	Do.
	100°	3.97	Perfect.	Do.
Orange.	10°	39.75	None.	Inconstant.
	40°	9.95	Do.	Perfect.
	60°	6.65	Little.	Do.
	160°	2.49	None.	Do.
Yellow.	8°	43.60	No decided lustre appears	Partial.
	15°	23.25		Good.
Blue.	8°	17.57	None appears.	Complete effect appears at once.
Violet.	8°	25.31	No appearance of lustre at all.	Imperfect.
	20°	10.12		Complete.
Purple.	15°	13.50	None appears.	With effort.
	40°	5.06		With ease.

TABLE XXXVI.—BLUE. OBSERVER, W.A.M.

Compared Colour.	Opening of the Episkotister Disc.	Ratio of the intensities of the objects presented to the respective Eyes.	Lustre	Stereoscopic Effect
Red.	15°	70.72	None.	Poor.
	50°	20.73	Do.	Partial.
	80°	12.96	Little.	With effort.
	90°	11.52	None.	Perfect.
Orange.	20°	51.84	None.	Partial.
	60°	17.28	Little.	Complete.
	90°	11.52	Better.	Do.
	220°	4.79	Very good.	Do.
Yellow	6°	148.80	None.	Partial.
	10°	89.28	Do.	Complete
	40°	22.32	Slight. (Never becomes good.)	Do.
Green.	15°	61.48	None.	With effort.
	60°	15.36	Little.	(Never combine perfectly.)
	140°	6.58	None.	
Violet.	6°	86.40	None appears.	Difficult.
	15°	34.56		Perfect.
Purple.	60°	8.64	None.	With effort, and so throughout.

TABLE XXXVII.—VIOLET. OBSERVER, W.A.M.

Compared Colour.	Opening of the Episkotister Disc.	Ratio of the intensities of the objects presented to the respective Eyes.	Lustre.	Stereoscopic Effect.
Red.	70° 140°	10.28 5.14	None.	Partial. Complete.
Orange.	20° 70°	36.00 10.28	None.	Partial. Complete.
Yellow.	40° 60°	15.50 10.36	None.	Partial. Complete.
Green.	20° 30°	32.00 21.33	None.	Partial. Complete.
Blue.	30° 80°	8.33 3.12	None.	Partial. Complete.
Purple.	15° 40° 90°	24.00 9.00 4.00	None. Slight. Very fair.	Partial. Better. Complete.

TABLE XXXVIII.—PURPLE. OBSERVER, W.A.M.

Compared Colour.	Opening of the Episkotister Disc.	Ratio of the intensities of the objects presented to the respective Eyes.	Lustre.	Stereoscopic Effect.
Red.	20° 90°	36.00 8.00	None.	Partial. Good.
Orange.	20° 60° 90°	36.00 12.00 8.00	None. Slight. Decided.	Imperfect. Complete. Do.
Yellow.	30° 70° 100°	20.66 8.85 6.20	None. None. Slight. (Never becomes good.	Partial. Good. Do.
Green.	80° 120°	8.00 5.33	None.	Partial. Perfect.
Blue.	60°	4.16	None.	At once complete.
Violet.	10° 20° 30° 60°	36.00 18.00 12.00 6.00	None. Slight. Do. Good.	Partial. Do. Good. Do.

TABLE XXXIX.—RED. OBSERVER, P.B.T.

Compared Colour.	Opening of the Episkotister Disc.	Ratio of the intensities of the objects presented to the respective Eyes.	Lustre.	Stereoscopic Effect.
Orange.	10°	36.00	None.	Partial.
	12½°	29.60	Slight.	Do.
	30°	12.00	Good.	Complete.
Yellow.	10°	31.00	None.	Complete.
	20°	15.50	Slight.	Do.
	50°	6.20	Good.	Do.
Green.	12°	26.66	None.	Slight.
	20°	16.00	Do.	Good.
	80°	4.00	Partial.	Do.
Blue.	10°	12.50	None.	Partial.
	23°	5.43	Do.	Complete.
Violet.	6°	30.00	None.	Partial.
	17½°	10.28	Do.	Complete.
	30°	6.00	Good.	Do.
Purple.	15°	12.00	None.	Partial.
	30°	6.00	Do.	Complete.

TABLE XL.—ORANGE. OBSERVER, P.B.T.

Compared Colour.	Opening of the Episkotister Disc.	Ratio of the intensities of the objects presented to the respective Eyes.	Lustre.	Stereoscopic Effect.
Red.	6° 150°	60.00 2.40	None. *Traces.	Complete. Do.
Yellow.	10° 20°	31.00 16.50	None. Do.	Partial. Complete.
Green.	10° 60°	32.00 5.33	None. Same, never becomes good.	Complete. Do.
Blue.	6° 12° 20°	20.83 10.41 6.25	None. Fair. Good.	Complete. Do. Do.
Violet.	12° 200°	15.00 1.11	None. *Slight traces.	Complete. Do.
Purple.	6° 15° 50° 60°	30.00 12.00 3.60 3.00	None. Do. Do. Slight.	Slight. Fair. Good.

* Hard to distinguish lustre from brightness of the object.
** Increases with greater intensity of Orange, but never becomes very decided.

TABLE XLI.—YELLOW. OBSERVER, P.B.T.

Compared Colour.	Opening of the Episkotister Disc.	Ratio of the intensities of the objects presented to the respective Eyes.	Lustre.	Stereoscopic Effect.
Red.	8° 40° 100°	52.25 10.45 4.18	Slight. Good. Very good.	Slight. Complete. Do.
Orange.	6° 15°	69.67 27.87	None. Do.	Partial. Complete.
Green.	12½°	29.72	None.	Complete.
Blue.	6° 10°	24.19 14.51	None. *Slight.	Imperfect. Complete.
Violet.	6° 10° 130°	34.83 20.25 1.55	None. Do. Extremely Slight.	Partial. Complete. Do.
Purple.	8° 30° 50°	25.48 6.96 4.18	None. Do. Slight.	Partial. Good. Do.

* Above 10° there was lustre—sometimes more, sometimes less decided—but never perfect.

TABLE XLII.—GREEN. OBSERVER, P.B.T.

Compared Colour.	Opening of the Episkotister Disc.	Ratio of the intensities of the objects presented to the respective Eyes.	Lustre.	Stereoscopic Effect.
Red.	8° 12° 160°	50.62 33.74 2.53	None. Do. Very slight.	Partial. Complete. Do.
Orange.	12° 40°	33.75 10.12	None. Do.	Partial. Complete.
Yellow.	15° 40°	23.25 8.72	None. Do.	Partial. Complete.
Blue.	10°	14.06	None.	Complete.
Violet.	10° 15°	20.25 13.50	None. Do.	Imperfect. Complete.
Purple.	12° 20° 60°	16.89 10.11 3.37	None. Do. Faint.	Partial. Complete. Do.

TABLE XLIII.—BLUE. OBSERVER, P.B.T.

Compared Colour.	Opening of the Episkotister Disc.	Ratio of the intensities of the objects presented to the respective Eyes.	Lustre.	Stereoscopic Effect.
Red.	8° 30°	129.60 34.56	None. Do.	Partial. Complete.
Orange.	20° 40° 70°	51.84 25.92 14.83	None. Slight. Good.	Partial. Complete.
Yellow.	8° 10°	111.60 89.28	None. Slight, never becomes good	Partial. Complete.
Green.	25°	36.80	None.	*Complete.
Violet.	20° 50°	25.92 10.36	None. Do.	*Partial. Complete.
Purple.	50° 90°	10.36 5.76	None. Do.	*Slight. Fair.

*Blue very dark, lines not clearly visible with smaller openings.

TABLE XLIV.—VIOLET . OBSERVER, P.B.T.

Compared Colour.	Opening of the Episkotister Disc.	Ratio of the intensities of the objects presented to the respective Eyes.	Lustre.	Stereoscopic Effect.
Red.	8° 20° 60°	90.00 36.00 12.00	None. " Slight.	Imperfect. Complete. Do.
Orange.	20° 60° 100°–160°	36.00 12.00 7.20–4.50	None. Do. *Faint.	Imperfect. Complete. Do.
Yellow.	8° 20° 60° 190°	77.50 31.00 10.33 3.55	None. Do. Faint. Disappears.	Partial. Complete. Do. Do.
Green.	10° 20°	64.00 32.00	None. Do.	Partial. Complete.
Blue.	15° 80°	16.66 3.12	None. Very faint.	Complete. Do.
Purple.	15° 70°	24.00 5.14	None. Do.	Fair. Perfect.

*Gradually fades as opening increases beyond 160 degrees.

TABLE XLV.—PURPLE. OBSERVER, P.B.T.

Compared Colour.	Opening of the Episkotister Disc.	Ratio of the intensities of the objects presented to the respective Eyes.	Lustre.	Stereoscopic Effect.
Red.	12° 70°	60.00 10.28	None. Do.	Partial. Complete.
Orange.	15° 20° 60°	48.00 36.00 12.00	None. Fair. Do.	Partial. Do. Complete.
Yellow.	12° 17½° 20°	52.00 36.51 31.00	None. Slight. Do.	Imperfect. Do. Complete.
Green.	12° 20° 50	53.33 32.00 12.80	None. Do. Slight.	Partial. Complete. Do.
Blue.	20° 120°	12.50 2.08	None. Do.	Complete. Do.
Violet.	20° 240°	18.00 1.12	Faint. Increases, but still weak.	Complete. Do.

TABLE XLVI.—WHITE. OBSERVER, W.
(WHITE CHANGING IN INTENSITY, COLOUR CONSTANT.)

Compared Colour.	Opening of the Episkotister Disc.	Ratio of the intensities of the objects presented to the respective Eyes.	Lustre.	Stereoscopic Effect.
Red.	1°	360.00	None.	Partial.
	4°	90.00	Do.	Complete.
	28°	12.85	Faint.	Do.
	210°–270°	1.71–1.33	Good.	Do.
Orange.	2°	180.00	None.	Complete.
	9°	40.00	Faint (never becomes good)	Do.
				Do.
Yellow.	2°	155.00	None.	Complete.
	10°	31.00	Slight.	Do.
Green.	4°	80.00	None.	Complete.
	10°	32.00	Faint.	Do.
	260°	1.23	Very good.	Do.
Blue.	2°	62.50	None.	Complete.
	6°	20.83	Slight.	Do.
	15°	8.33	Very fair.	Do.
Violet.	2°	90.00	None.	Partial.
	4°	45.00	Do.	Complete.
	7°	25.71	Slight.	Do.
	110°	1.63	Brighter	Do.
	250°	.72	Good.	Do.
Purple.	1°	180.00	None.	Partial.
	4°	45.00	Do.	Complete.
	8°	22.50	Slight.	Do.
	30°	6.00	Better.	Do.
	80°	2.22	Very good.	Do.

TABLE XLVII.—WHITE. OBSERVER, W.
(WHITE CONSTANT IN INTENSITY, COLOUR CHANGING).

Compared Colour.	Opening of the Episkotister Disc.	Ratio of the intensities of the objects presented to the respective Eyes.	Lustre.	Stereoscopic Effect.
Red.	2°	180.00	None.	Imperfect.
	4°	90.00	Do.	Complete.
	8°	45.00	Slight.	Do.
	95°	3.78	Very good.	Do.
Orange.	2°	180.00	None.	Complete.
	8°	45.00	Slight.	Do.
	24°	15.00	Fair.	Do.
Yellow.	2°	209.03	None.	Complete.
	10°	41.80	Slight.	Do.
	130°	3.21	Fair.	Do.
Green.	2°	202.50	None.	Partial.
	4°	101.25	Do.	Complete.
	16°	25.31	Slight.	Do.
	65°	6.23	Fair.	Do.
Blue.	1°	1036.80	None.	Imperfect.
	3°	345.60	Do.	Complete.
	6°	172.80	Slight.	Do.
	100°	10.36	Fair.	Do.
Violet.	2°	360.00	None.	Complete.
	14°	51.42	Slight.	Do.
Purple.	1°	720.00	None.	Imperfect.
	4°	180.00	Extremely faint.	Complete.
	12°	60.00	Slight.	Do.
	100°	7.20	Good.	Do.

Results : Comparison of the results of these experiments with those of the similar experiments in white light shows some very interesting points of difference.

(1) With a considerable number of combinations no lustre appeared, no matter what the difference of intensity. (The limits were from equality to a ratio of 1 to 720). This seems difficult to account for, the more so as there is not very much regularity as to the colour combinations with which the lustre appears or fails. On the whole, it may perhaps be said that in most of the cases where no lustre appears the colours are either somewhat near each other in quality, so as to mix readily, or else are nearly complementary, so as to produce the strongest rivalry. The number of experiments, however, was not great enough, nor the regularity of the results sufficient, to make this induction conclusive.

2. Lustre does occur in many cases with smaller differences of brightness between the two retinal impressions than were required with uncoloured light to produce it. As before observed, when "good" lustre was once seen it continued till the disc was opened to its fullest extent. And in some cases, as when, for example, red was behind the disc and green on the other side, this meant that the intensities were practically equal. The lustre was frequently reported as "good" or "decided" when the intensities of the images were about as 3 or 4 to 1. With uncoloured light, on the contrary, no lustre at all appeared unless one retinal image was from 1½ to 3 times as bright as the other; and "good" lustre required a ratio of at least 9 or 10 to 1.

3. Lustre does not occur with as great differences of intensity in coloured as in uncoloured light. That is to say, the upper limit is much lower with coloured light. The lustre was scarcely ever good when one impression was more than 10 or 12 times as bright as the other, and a ratio of about 50 to 1 is the extreme upper limit for the appearance of any lustre at all. With uncoloured light, on the other hand, the upper limit for good lustre varied from 375 to 920 to 1 and for any lustre at all the upper limit was about 1900 to 1.

4. The opening of the disc required for the production of the stereoscopic effect is greater when the images differ in both colour and brightness than when they differ in brightness only. The complete combination often required an opening of 30° or 40°, or even more, while not even a partial or inconstant combination in many cases appeared with an opening less than 15° or 20°; whereas reference to the corresponding tables regarding uncoloured light shows that a partial stereoscopic effect appeared with an opening of 2½° to 9°, and the complete effect did not require an opening greater than 14° to 18°. From Tables XLVI and XLVII it will be seen that this phenomenon re-appears even in the combination of white and coloured light. A partial stereoscopic effect was frequently seen with an opening of only 1°, and complete stereoscopic combination commonly did not require more than 4°.

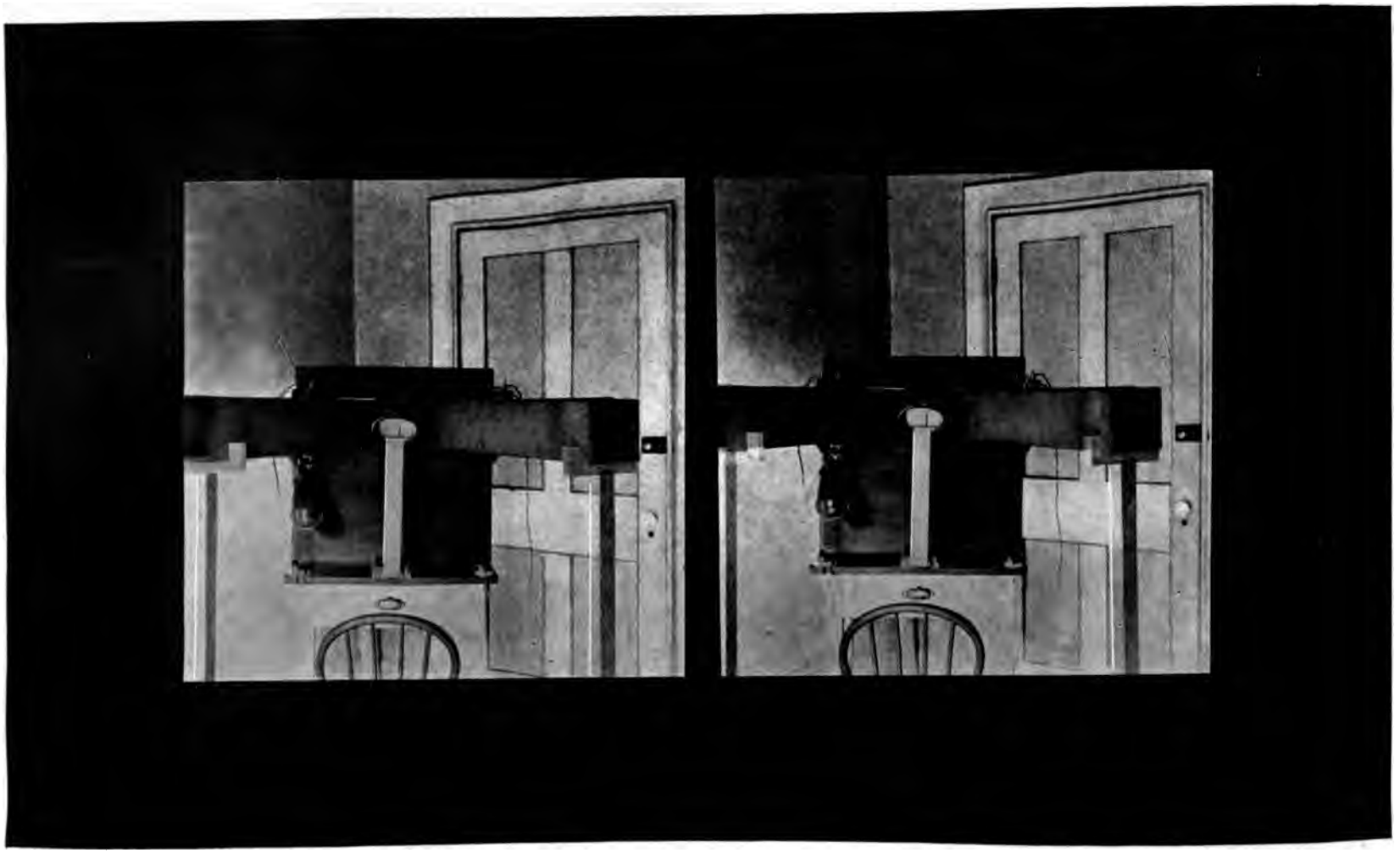


FIG. I.

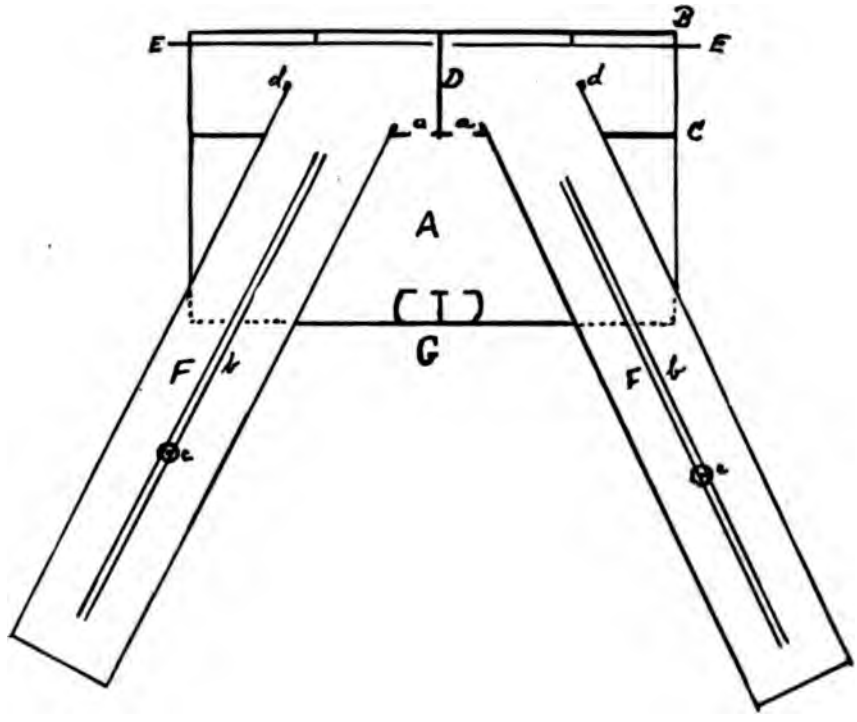


FIG. II

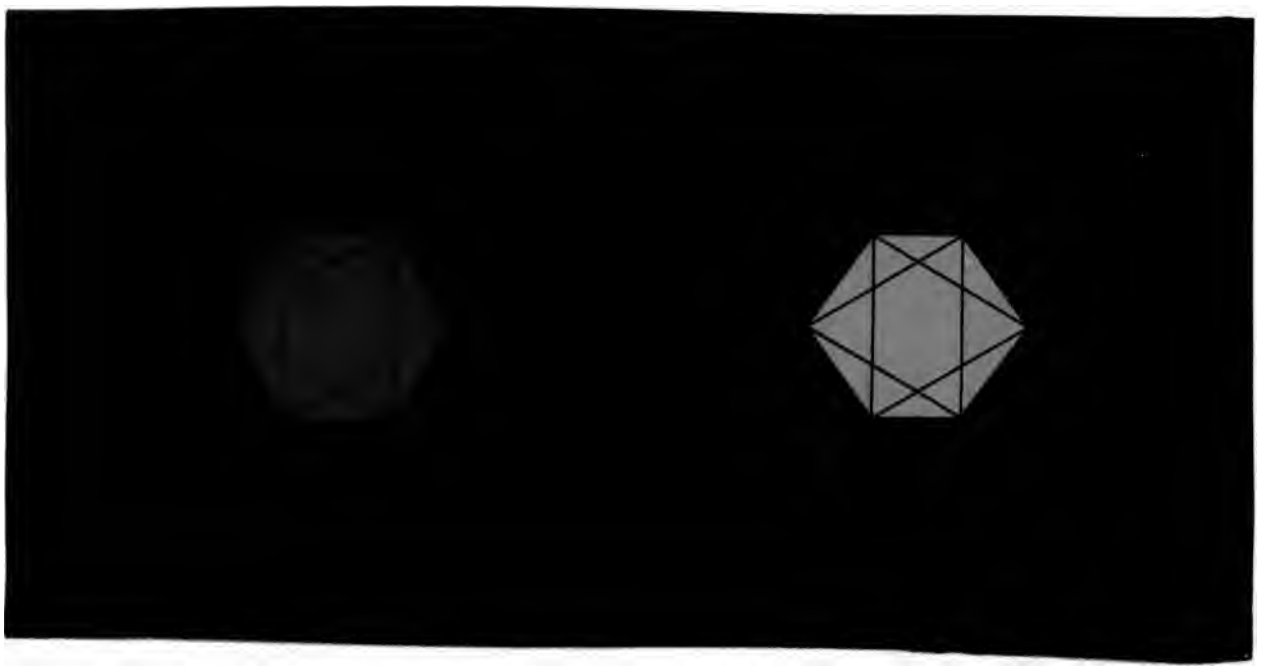


FIG. III

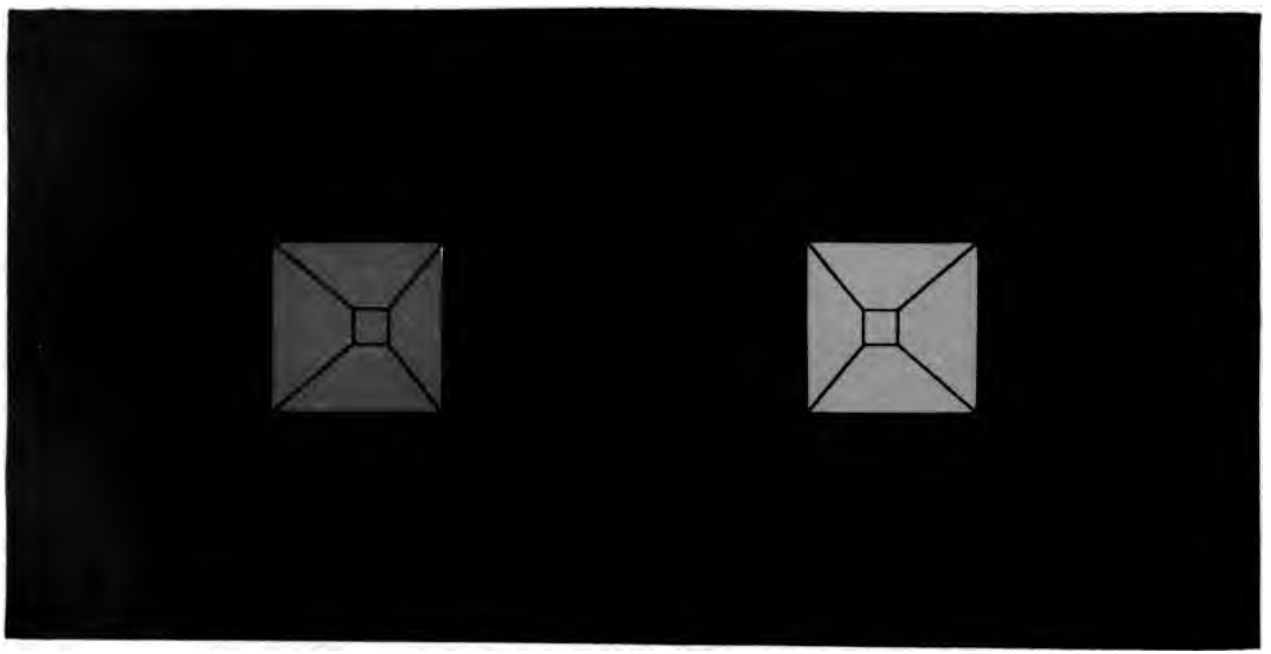


FIG. IV

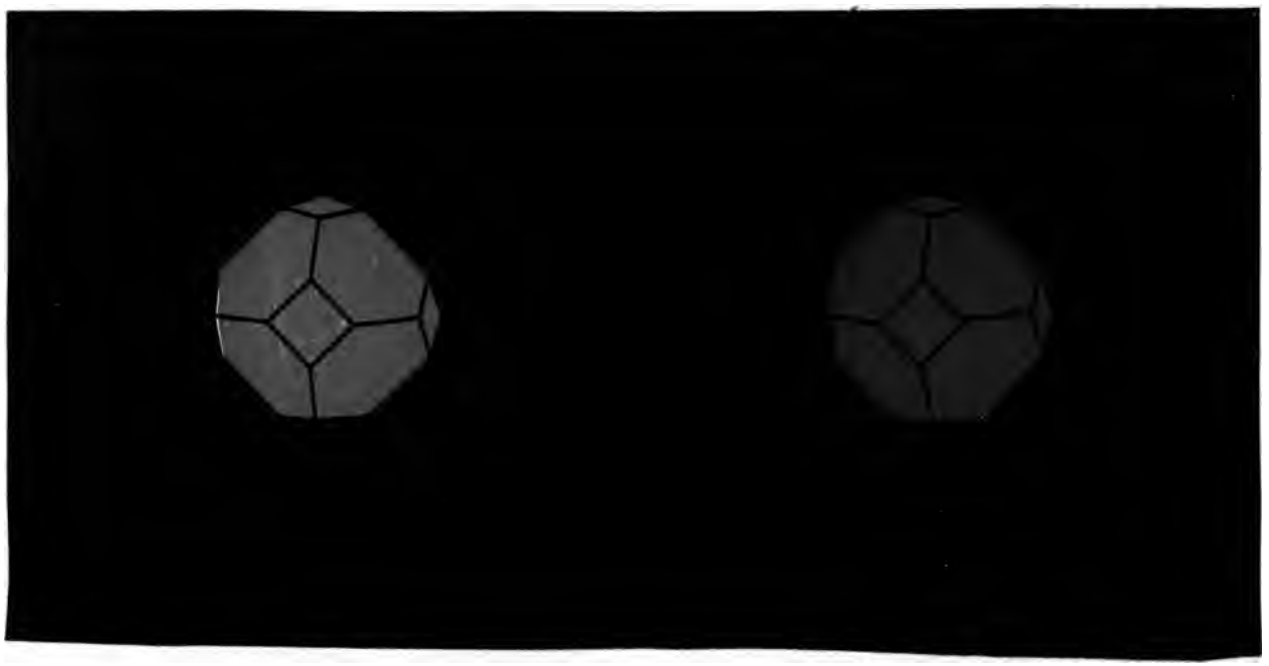
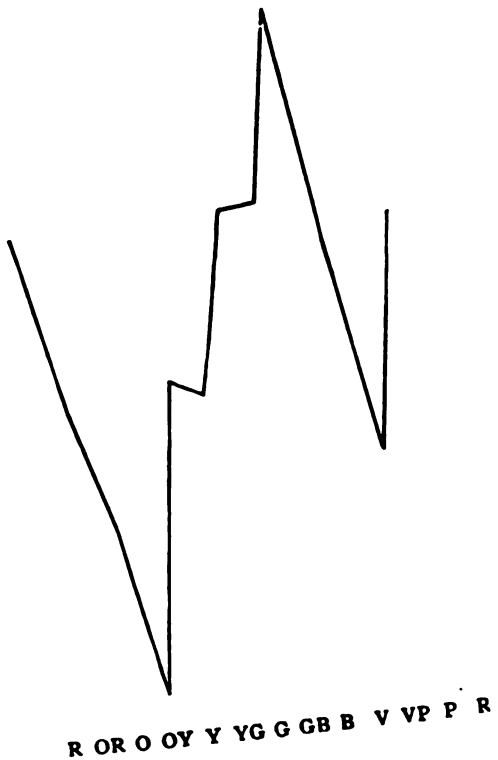
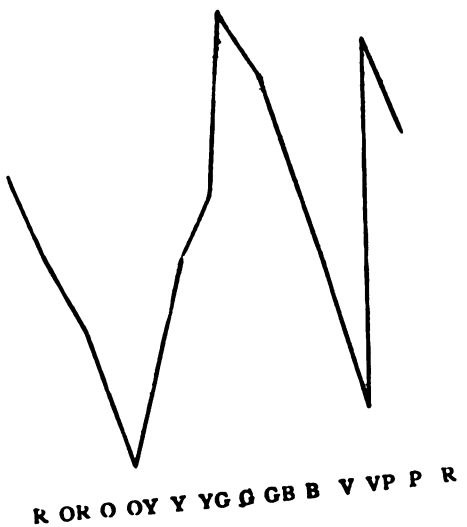


FIG. V

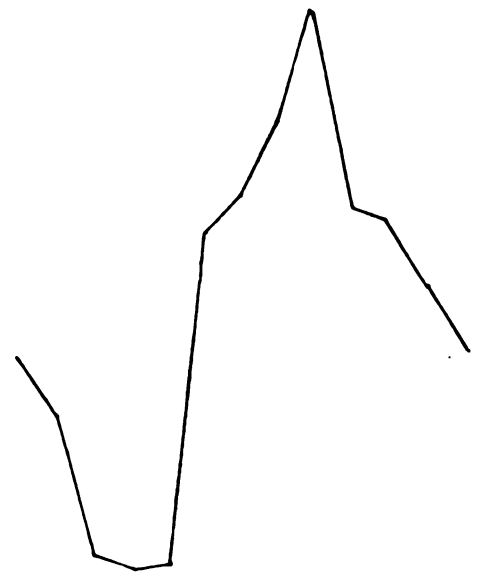


CURVE I.—CASES
(Tables III–VI)



CURVE II.—COLOURS
(Tables III–VI)

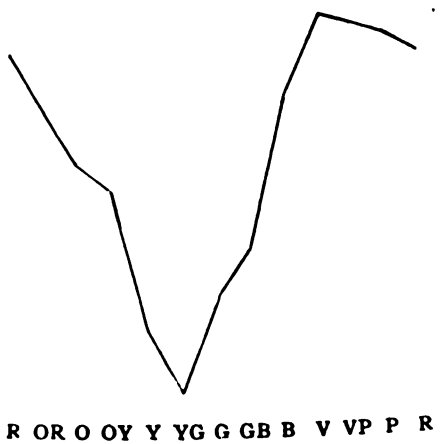
PLANE SURFACES



CURVE III.—CASES
(Tables IX–XII)

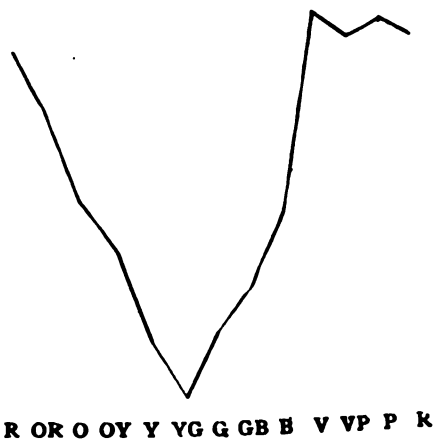
CURVE IV.—COLOURS
(Tables IX–XII)

STEREOSCOPIC OBJECTS



CURVE V
(Tables XXVI and XXVII)

CURVE VI
(Table XVIII)



CURVE VII
(Tables XXVI–XXVIII)

COLOURED AND UNCOLOURED OBJECTS

COLOUR AESTHETICS

(SECOND ARTICLE)

COMBINATIONS OF COLOURS, TINTS AND SHADES

BY

F. LOUIS BARBER, M.A., PH.D.

BINARY COMBINATIONS OF TINTS AND SHADES AMONG THEMSELVES AND WITH ONE ANOTHER.

In the first article we have treated the combinations of colours in full saturation with tints and shades. We have now to examine the aesthetic characteristics embraced in the combinations of shades with shades, tints with tints, shades with tints, and tints with shades. The room, the means of experiment and method employed were the same as used in the examination of colours with tints and shades. The same may be said with regard to the time of day, instructions to the observers and all other conditions; but the number of observers was twenty-three instead of ten, and thus a larger number of judgments was obtained. There are four distinct sets of experiments. In the first two sets, concerning the combination of the shades with themselves, and the tints with themselves, the number of binary combinations judged was 24 x 23 x 23 x 2, or a total of 25,392. The other two series refer to the combinations of the tints with shades and the shades with tints. In these two latter sets of experiments the number of judgments was 24 x 24 x 23 x 2, or 26,496; and thus there is a grand total for the four series of 51,888 combinations judged.

As in the preceding paper on combinations of tints and shades with colours, the results are here represented by tables, and, in order that their significance may be more easily seen, by curves also. Tables xiii and xiv give the numbers of "pleasant" and "most pleasant" respectively for each shade with all the other shades, xv and xvi the selections of combinations of tints similarly, while xvii and xviii show the result of each shade combined with each tint. Tables xiii, xv and xvii refer to "pleasant" combinations, whilst xiv, xvi and xviii have to do with the "most pleasant." For the sake

of simplicity we combine three colours in one curve. Thus Curv XLI stands for red, including colours 1, 2 and 3. Tables xi to xxvi, corresponding to these curves, thus represent th former Tables combined by threes; e.g. in xix the capabilit of each shade (three combined) to form pleasant combination is shown in the eight horizontal columns. What this means ma be more easily seen in Figs. XLI to LXIV, where each curv is a diagrammatic representation of the average of the thre combined qualities, e.g. in red.

As in the previous paper, where a curve had been drawn fo each individual colour, each tint or shade is now represented b a curve, giving 96 single curves for the pleasant, and 96 for th most pleasant. All of these cannot be reproduced in this article But as an example a number of these curves are given in Figs XXIII to XXX. In every case the upper curve represents th "pleasant," and the lower one the "most pleasant." Th abscissæ show the colour-qualities in spectral order, while th ordinates indicate the frequency with which the tints have bee chosen with tints, the shades with the shades, the shades witl the tints, or vice versa. The cross (x) indicates the positio of the complementary. The scale of the abscissa is twice tha of the ordinate. In addition, four figures have been draw (Figs. LXV to LXVIII) indicating for all the 24 colours th total frequency of their selection in these experiments, whicl may stand as a measurement of their ability to produce agreeabl combinations.

It was said in the previous paper, in reference to combination of colours with the tints and shades, that the maximum of plea santness for the colours with the tints and that for the colours witl the shades should not be expected always to occur in the sam part of the spectrum.* The results of the experiments witl shades and tints indicate that there is a difference in the positio of the maximum of pleasantness, corresponding, more or less to the change of intensity, through the series of tints, colour and shades, and the regularity with which this change take place supplies a significant verification of Purkinje's phenom enon.

* See University of Toronto Studies, Psych. Series, Vol. II, No. 3, p. 14 [178].

TABLE XIII.

SHADES WITH SHADES.

PLEASANT COMBINATIONS.

No. of Shades.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	Shades
1		12	10	8	9	13	13	13	14	19	25	25	20	15	10	9	9	8	10	4	6	6	6	10	274
2	12		5	5	7	12	15	20	25	28	27	31	26	15	15	10	11	7	10	6	5	5	4	8	309
3	10	5		6	9	7	8	10	13	19	23	28	23	10	12	5	8	7	6	4	5	2	3	4	227
4	8	5	6		14	10	8	9	12	20	22	15	19	8	6	8	9	6	5	3	2	3	5	5	208
5	9	7	9	14		13	8	10	8	19	22	18	17	14	7	4	7	7	8	6	3	3	4	6	223
6	13	12	7	10	13		7	10	15	20	19	15	14	10	9	7	9	8	7	8	7	6	6	6	238
7	13	15	8	8	8	7		12	9	11	17	16	15	16	9	8	11	9	4	5	3	7	10	8	229
8	13	20	10	9	10	10	12		12	20	16	19	19	16	9	13	9	13	5	9	9	9	13	13	288
9	14	25	13	12	8	15	9	12		17	27	24	23	20	13	17	16	20	9	13	16	12	16	14	365
10	19	28	19	20	19	20	11	20	17		18	23	19	15	13	16	15	14	8	11	12	14	19	14	384
11	25	27	23	22	22	19	17	16	27	18		18	20	16	18	16	20	16	15	15	13	14	20	25	442
12	25	31	28	15	18	15	16	19	24	23	18		14	14	13	12	20	17	11	9	8	13	18	18	399
13	20	26	23	19	17	14	15	19	23	19	20	14		11	13	12	14	14	12	10	9	15	18	18	375
14	15	15	10	8	14	10	16	16	20	15	16	14	11		16	14	15	14	10	7	4	7	13	15	295
15	19	15	12	6	7	9	9	9	13	13	18	13	13	16		10	9	10	5	2	4	5	8	10	226
16	9	10	5	8	4	7	8	13	17	16	16	12	12	14	10		5	7	4	0	3	3	8	6	197
17	9	11	8	9	7	9	11	9	16	15	20	20	14	15	9	5		5	4	1	1	2	7	9	216
18	8	7	7	6	7	8	9	13	20	14	16	17	14	14	10	7	5		9	2	4	4	5	9	215
19	10	10	6	5	8	7	4	5	9	8	15	11	12	10	5	4	4	9		5	3	2	4	6	162
20	4	6	4	3	6	8	5	9	13	11	15	9	10	7	2	0	1	2	5		7	4	2	6	139
21	6	5	5	2	3	7	3	9	16	12	13	8	9	4	4	3	1	4	3	7		8	3	1	136
22	6	5	2	3	3	6	7	9	12	14	14	13	15	7	5	3	2	4	2	4	8		5	5	154
23	6	4	3	5	4	6	10	13	16	19	20	18	18	13	8	8	7	5	4	2	3	5		9	206
24	10	8	4	5	6	6	8	13	14	14	25	18	18	15	10	6	9	9	6	6	1	5	9		225
																								Total....	6132

TABLE XIV.

SHADES WITH SHADES.

MOST PLEASANT COMBINATIONS.

No. of Shades.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	Shades
1		2	1	3	2	2	3	2	2	7	8	11	11	5	4	0	2	3	1	1	0	3	3	4	80
2	2		1	1	0	1	3	6	7	10	12	10	12	4	3	4	5	5	3	3	2	1	1	2	98
3	1	1		3	1	2	2	2	2	5	5	5	8	2	2	0	1	1	1	0	0	1	0	1	46
4	3	1	3		8	1	2	1	2	4	7	6	7	0	0	1	1	1	1	0	0	0	0	0	49
5	2	0	1	8		4	2	1	3	5	8	8	7	3	0	0	0	2	1	2	0	0	1	3	61
6	2	1	2	1	4		1	1	3	9	8	8	6	2	1	2	0	3	2	3	1	0	1	3	64
7	3	3	2	2	2	1		3	1	1	4	3	6	0	1	1	4	3	1	0	2	1	4	2	50
8	2	6	2	1	1	1	3		2	2	2	5	6	3	1	1	2	4	2	3	1	2	4	6	62
9	2	7	2	2	3	3	1	2		4	7	4	4	5	1	4	5	7	4	5	3	3	3	2	83
10	7	10	5	4	5	9	1	2	4		5	4	3	5	3	5	4	3	4	4	2	4	2	5	100
11	8	12	5	7	8	8	4	2	7	5		7	2	3	3	4	8	3	5	5	4	3	7	6	126
12	11	10	5	6	8	8	3	5	4	4	7		3	3	2	1	2	3	3	3	3	8	9	9	120
13	11	12	8	7	7	6	6	6	4	3	2	3		3	2	2	1	1	1	4	2	3	1	6	101
14	5	4	2	0	3	2	0	3	5	5	3	3	3		1	3	5	7	2	3	2	3	3	6	73
15	4	3	2	0	0	1	1	1	1	3	3	2	2	1		1	2	1	1	0	2	1	2	5	39
16	0	4	0	1	0	2	1	1	4	5	4	1	2	3	1		1	0	1	0	2	1	1	0	35
17	2	5	1	1	0	0	4	2	5	4	8	2	1	5	2	1		2	0	0	1	0	0	0	46
18	3	5	1	1	2	3	3	4	7	3	3	3	1	7	1	0	2		0	0	1	1	1	1	53
19	1	3	1	1	1	2	1	2	4	4	5	3	1	2	1	1	0	0		2	1	1	1	4	42
20	1	3	0	0	2	3	0	3	5	4	5	3	4	3	0	0	0	0	2		4	0	0	2	44
21	0	2	0	0	0	1	2	1	3	2	4	3	2	2	2	2	1	1	1	4		1	1	1	36
22	3	1	1	0	0	0	1	2	3	4	3	8	3	3	1	1	0	1	1	0	1		2	1	40
23	3	1	0	0	1	1	4	4	3	2	7	9	1	3	2	1	0	1	1	0	1	2		4	51
24	4	2	1	0	3	3	2	6	2	5	6	9	6	6	5	0	0	1	4	2	1	1	4		73
																								Total....	1572

TABLE XV.

TINTS WITH TINTS.

PLEASANT COMBINATIONS.

No. of Tints.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	Tints.
1		6	3	6	13	12	16	14	22	18	20	24	18	17	11	11	8	5	5	4	3	1	1	3	241
2	6		9	10	16	13	14	13	16	15	17	25	20	16	13	11	8	7	7	5	4	1	2	1	249
3	3	9		9	19	13	14	12	15	17	15	24	21	16	11	9	8	6	5	3	4	2	2	2	239
4	6	10	9		9	9	9	16	13	16	17	20	21	17	16	14	6	10	8	8	6	7	5	5	257
5	13	16	19	9		10	14	10	11	14	18	17	23	16	16	12	10	10	11	13	12	9	7	6	296
6	12	13	13	9	10		11	11	11	17	19	18	20	15	15	12	8	8	14	16	13	10	10	11	296
7	16	14	14	9	14	11		9	11	14	18	17	16	17	16	12	12	11	14	12	10	14	9	11	301
8	14	13	12	16	10	11	9		12	11	12	18	19	17	18	17	18	15	17	14	16	13	12	9	323
9	22	16	15	13	11	11	11	12		11	18	21	17	13	18	12	20	18	14	14	17	16	16	13	349
10	18	15	17	16	14	17	14	11	11		11	19	14	12	15	10	18	13	15	14	18	16	13	15	336
11	20	17	15	17	18	19	18	12	18	11		15	15	15	9	7	13	13	13	14	18	15	14	19	345
12	24	25	24	20	17	18	17	18	21	19	15		10	17	15	13	17	15	16	13	19	11	16	14	394
13	18	20	21	21	23	20	16	19	17	14	15	10		18	13	13	14	14	13	14	19	12	18	18	380
14	17	16	16	17	16	15	17	17	13	12	15	17	18		13	13	14	17	13	17	14	13	21	17	358
15	11	13	11	16	16	15	16	18	18	15	9	15	13	13		14	13	14	10	11	12	14	17	11	315
16	11	11	9	14	12	12	12	17	12	10	7	13	13	13	14		10	10	10	9	7	6	12	8	252
17	8	8	8	6	10	8	12	18	20	18	13	17	14	14	13	10		7	3	3	5	7	11	8	241
18	5	7	6	10	10	8	11	15	18	13	13	15	14	17	14	10	7		5	6	5	6	7	7	229
19	5	7	5	8	11	14	14	17	14	15	13	16	13	13	10	10	3	5		5	5	6	10	9	228
20	4	5	3	8	13	16	12	14	14	14	14	13	14	17	11	9	3	6	5		7	4	7	7	220
21	3	4	4	6	12	13	10	16	17	18	18	19	19	14	12	7	5	5	5	7		6	5	4	229
22	1	1	2	7	9	10	14	13	16	16	15	11	12	13	14	6	7	6	6	4	6		3	1	193
23	1	2	2	5	7	10	9	12	16	13	14	16	18	21	17	12	11	7	10	7	5	3		3	221
24	3	1	2	5	6	11	11	9	13	15	19	14	18	17	11	8	8	7	9	7	4	1	3		202
																							Total....		6694

TABLE XVI.

TINTS WITH TINTS.

MOST PLEASANT COMBINATIONS.

No. of Tints.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	Tints.
1		0	0	2	1	0	3	1	6	2	6	10	6	8	1	2	2	2	0	0	1	0	0	0	53
2	0		2	3	1	1	2	3	2	2	1	7	2	6	2	2	0	0	0	1	0	0	0	0	37
3	0	2		2	3	3	2	1	1	2	3	4	4	5	3	2	2	1	0	0	0	0	0	0	40
4	2	3	2		3	2	2	0	2	1	6	7	4	8	3	1	2	4	0	4	1	2	0	0	59
5	1	1	3	3		1	4	1	2	3	6	3	10	5	4	4	3	3	3	4	2	4	2	3	75
6	0	1	3	2	1		6	2	0	3	3	2	5	4	2	8	3	3	4	3	3	2	0	1	61
7	3	2	2	2	4	6		4	2	1	4	2	7	3	2	3	2	1	2	1	4	1	1	3	62
8	1	3	1	0	1	2	4		3	1	3	2	3	2	4	4	5	4	3	0	4	2	3	1	56
9	6	2	1	2	2	0	2	3		1	3	2	5	8	2	1	4	3	2	4	6	3	3	1	66
10	2	2	2	1	3	3	1	1	1		4	4	2	2	2	1	4	1	3	3	1	4	1	4	52
11	6	1	3	6	6	3	4	3	3	4		4	3	4	0	0	2	4	2	4	8	2	2	5	79
12	10	7	4	7	3	2	2	2	2	4	4		3	4	5	3	3	2	3	3	4	3	8	3	91
13	6	2	4	4	10	5	7	3	5	2	3	3		10	4	0	1	4	4	3	4	3	5	7	99
14	8	6	5	8	5	4	3	2	8	2	4	4	10		6	4	5	9	6	5	7	4	13	9	137
15	1	2	3	3	4	2	2	4	2	2	0	5	4	6		2	6	5	4	4	2	7	8	7	85
16	2	2	2	1	4	8	3	4	1	1	0	3	0	4	2		3	1	3	3	1	4	4	3	59
17	2	0	2	2	3	3	2	5	4	4	2	3	1	5	6	3		1	0	1	0	3	3	1	56
18	2	0	1	4	3	3	1	4	3	1	4	2	4	9	5	1	1		2	2	0	3	1	1	57
19	0	0	0	0	3	4	2	3	2	3	2	3	4	6	4	3	0	2		0	2	2	0	1	46
20	0	1	0	4	4	3	1	0	4	3	4	3	3	5	4	3	1	2	0		4	1	3	2	55
21	1	0	0	1	2	3	4	4	6	1	8	4	4	7	2	1	0	0	2	4		3	1	4	62
22	0	0	0	2	4	2	1	2	3	4	2	3	3	4	7	4	3	3	2	1	3		1	1	55
23	0	0	0	0	2	0	1	3	3	1	2	8	5	13	8	4	3	1	0	3	1	1		3	62
24	0	0	0	0	3	1	3	1	1	4	5	3	7	9	7	3	1	1	1	2	4	1	3		60
																								Total....	1564

TABLE XVII.

SHADES WITH TINTS.

PLEASANT COMBINATIONS.

No. of Shades.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	Tints.
1	15	8	13	15	18	18	16	12	17	17	21	18	22	19	7	6	5	5	5	2	5	6	8	9	287
2	10	10	9	12	18	15	16	14	15	18	20	19	23	21	11	9	7	4	4	3	3	4	3	6	274
3	9	8	9	6	9	10	12	11	15	15	15	18	16	16	8	7	5	4	5	5	5	3	3	5	219
4	6	6	10	10	12	16	11	9	8	14	15	18	15	15	9	8	8	6	7	6	6	6	7	10	238
5	10	10	14	10	15	19	14	16	17	15	19	25	18	17	9	8	6	10	7	4	6	6	8	8	291
6	12	10	11	9	16	21	18	15	11	10	17	21	19	11	8	11	7	12	8	4	10	10	10	12	293
7	12	14	18	15	15	18	18	18	14	11	19	23	25	24	11	15	16	14	13	8	9	11	12	14	367
8	13	13	14	13	15	16	17	19	19	13	18	19	21	16	13	13	13	12	12	10	10	11	14	14	348
9	15	19	18	16	14	15	14	15	18	13	16	18	17	16	16	13	12	14	12	15	12	14	16	14	362
10	22	16	17	18	25	22	18	21	24	22	21	18	17	8	7	13	15	16	15	17	13	16	15	15	411
11	21	22	20	21	20	23	18	21	22	25	30	29	30	20	14	13	18	18	19	17	19	22	20	20	502
12	22	23	19	21	25	25	22	24	25	28	29	31	29	29	24	24	19	19	19	20	21	19	21	18	556
13	17	16	16	19	24	23	22	19	22	28	27	26	29	27	19	26	16	18	17	17	17	19	19	19	502
14	9	10	9	11	15	19	16	18	20	19	23	20	26	25	19	20	13	11	14	13	16	14	15	18	393
15	6	5	5	6	10	12	13	12	12	9	17	20	20	16	21	20	13	9	9	7	9	8	7	11	277
16	7	7	10	11	14	16	15	12	23	13	18	18	18	18	16	15	17	15	18	7	3	4	7	8	310
17	8	6	7	9	10	13	11	11	14	21	19	20	17	17	17	17	20	18	12	6	4	6	6	4	293
18	8	6	8	9	10	14	13	12	13	20	20	20	15	12	15	15	18	20	16	11	6	8	10	12	311
19	10	6	9	8	10	14	9	10	13	16	18	19	15	13	13	14	16	18	21	15	9	7	9	8	300
20	7	5	9	9	11	14	10	12	14	14	14	14	14	10	7	10	7	9	11	12	11	13	11	9	257
21	7	5	5	8	8	9	5	11	12	10	14	13	14	10	7	9	5	6	8	11	10	9	8	7	211
22	6	5	3	7	10	12	13	12	13	12	18	20	17	13	6	6	2	4	5	8	9	11	5	6	223
23	12	11	7	8	12	18	16	14	14	17	18	19	22	17	10	6	5	5	6	3	5	2	7	9	263
24	13	9	6	8	17	18	16	16	15	20	21	20	24	18	9	6	5	4	5	3	7	5	6	10	281
Total	277	250	266	279	353	400	353	354	390	400	467	486	483	408	296	304	268	271	268	224	225	234	247	266	7769

TABLE XVIII.

SHADES WITH TINTS.

MOST PLEASANT COMBINATIONS.

No. of Shades.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	Tints.
1	4	4	4	8	9	4	3	4	4	5	5	6	6	7	1	1	1	1	1	1	2	2	2	1	86
2	2	2	1	1	4	2	1	2	4	6	6	6	3	8	2	3	0	0	1	0	0	1	2	1	58
3	1	3	2	2	1	0	1	3	2	2	8	4	2	5	2	1	0	0	0	0	1	2	3	2	47
4	1	2	0	3	1	2	1	4	3	3	5	5	2	2	2	2	0	0	0	1	1	1	1	0	42
5	1	2	3	4	6	5	4	7	4	5	7	6	3	6	0	2	1	0	0	0	0	1	3	1	71
6	4	3	4	3	6	6	2	3	3	7	5	8	3	3	0	1	1	2	1	0	1	1	1	1	69
7	2	4	7	0	4	3	8	3	2	2	4	5	2	2	2	0	2	3	1	2	1	4	4	5	72
8	3	6	4	1	0	1	3	5	5	2	7	4	3	1	4	4	2	3	1	2	1	2	6	4	74
9	4	8	2	3	3	4	1	3	6	5	1	4	5	4	6	6	2	1	1	4	9	6	7	3	98
10	5	7	5	12	6	5	6	9	6	7	7	4	3	1	1	1	1	4	5	6	7	6	8	9	131
11	7	9	6	8	4	8	6	4	8	9	12	19	9	5	5	3	7	10	4	6	6	10	9	10	184
12	7	11	7	8	10	6	8	6	7	6	10	11	13	9	7	8	7	4	8	8	9	4	12	8	194
13	6	5	4	2	4	3	2	3	4	4	10	8	9	9	4	13	4	4	4	7	4	5	6	9	133
14	1	3	2	1	1	3	3	3	1	3	4	6	13	8	6	6	4	2	1	0	5	2	4	6	88
15	1	2	1	1	2	2	3	2	4	3	2	7	7	6	4	6	2	2	4	2	1	1	2	2	69
16	3	2	2	2	4	2	3	1	0	2	2	5	3	3	6	5	3	2	5	1	0	1	1	2	60
17	2	3	4	3	4	4	2	0	2	3	6	5	6	5	3	3	4	5	5	2	3	2	2	2	80
18	0	3	0	1	3	3	2	2	1	1	5	4	3	2	1	4	3	6	5	2	1	1	2	1	56
19	1	3	2	0	2	0	0	2	3	3	5	3	5	1	2	5	2	3	6	6	2	2	1	1	60
20	1	2	3	0	2	1	0	2	2	2	3	4	4	2	1	4	1	3	3	4	5	4	2	2	57
21	2	3	1	0	0	1	0	2	1	3	7	2	7	2	1	1	0	1	1	0	3	3	4	1	46
22	2	0	0	2	2	1	0	2	2	5	5	5	9	2	1	2	1	1	1	2	3	3	1	1	53
23	3	2	4	1	3	5	2	2	1	5	6	7	8	7	3	1	2	0	1	1	2	1	0	1	68
24	5	4	3	4	5	1	2	2	1	4	5	5	4	5	1	0	1	0	1	1	1	2	1	0	58
Total	68	93	71	70	86	72	63	76	76	97	137	143	132	105	65	82	51	57	60	58	68	67	84	73	1954

TABLE XIX.

SHADES WITH SHADES.

PLEASANT.

Shades.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	Shades.
Red	22	17	15	19	25	32	36	43	52	66	75	84	69	40	37	24	28	22	26	14	16	13	13	22	
Orange	30	24	22	24	27	23	23	29	35	59	63	48	50	32	22	19	25	21	20	17	12	12	15	17	
Yellow	40	60	31	29	26	32	21	24	21	48	60	59	57	52	31	38	36	42	18	27	28	28	39	35	
Yel.-Green ..	69	86	70	57	59	54	44	55	68	41	36	41	53	45	44	44	55	47	34	35	33	41	57	57	
Blue-Green .	45	56	45	33	38	33	40	44	56	47	54	41	24	27	29	36	38	38	27	19	17	27	39	43	
Blue	26	28	20	23	18	24	28	35	53	45	52	49	40	43	29	12	10	12	17	3	8	9	20	24	
Violet	20	21	15	10	17	22	12	23	38	31	43	28	31	21	11	7	6	15	8	12	10	14	9	13	
Purple	22	17	9	13	13	18	25	35	42	47	59	49	51	35	23	17	18	18	12	12	12	10	14	14	

TABLE XX.

SHADES WITH SHADES.

MOST PLEASANT.

Shades.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	Shades.
Red	3	3	2	7	3	5	8	10	11	22	25	26	31	11	9	4	8	9	5	4	2	5	4	7	
Orange	7	2	6	9	12	5	5	3	8	18	23	22	20	5	1	3	1	6	4	5	1	0	2	6	
Yellow	7	16	6	5	6	5	4	5	3	7	13	12	16	8	3	6	11	14	7	8	6	6	11	10	
Yel.-Green ..	26	32	15	17	21	25	8	9	15	9	12	11	8	11	8	10	14	9	12	12	9	15	18	20	
Blue-Green .	20	19	12	7	10	9	7	10	10	11	8	8	5	4	3	6	8	9	4	7	6	7	6	17	
Blue	5	14	2	3	2	5	8	7	16	12	15	6	4	15	4	1	3	2	1	0	4	2	2	1	
Violet	2	8	1	1	3	6	3	6	12	10	14	9	7	7	3	3	1	1	3	6	5	2	2	7	
Purple	10	4	2	0	4	4	7	12	8	11	16	26	10	12	8	2	0	3	6	2	3	3	6	5	

TABLE XXI.

TINTS WITH TINTS.

PLEASANT.

Tints.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	Tints
Red	9	15	12	25	48	38	44	39	53	50	52	73	59	49	35	31	24	18	17	12	11	4	5	6	
Orange	31	39	41	18	19	19	34	37	35	47	54	55	64	48	47	38	24	28	33	37	31	26	22	22	
Yellow	52	43	41	38	35	33	20	21	23	36	48	56	52	47	52	41	50	44	45	40	43	43	37	33	
Yel.-Green ..	62	57	56	53	49	54	49	41	50	30	26	34	39	44	39	30	48	41	44	41	55	42	43	48	
Blue-Green .	46	49	48	54	55	50	49	54	48	41	39	42	31	31	26	40	41	45	36	42	45	39	56	46	
Blue	24	26	23	30	32	28	35	50	50	41	33	45	41	44	41	20	17	17	18	18	17	19	30	23	
Violet	12	16	12	22	36	43	36	47	45	47	45	48	46	44	33	26	11	16	10	12	12	16	22	20	
Purple	5	4	6	17	22	31	34	34	45	44	48	41	48	51	42	26	26	20	25	18	15	4	6	4	

TABLE XXII.

TINTS WITH TINTS.

MOST PLEASANT.

Tints.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	Tints
Red	0	2	2	7	5	4	7	5	9	6	10	21	12	19	6	6	4	3	0	1	1	0	0	0	
Orange	3	5	8	5	4	3	12	3	4	7	15	12	19	17	9	13	8	10	7	11	6	8	2	4	
Yellow	10	7	4	4	7	8	6	7	5	3	10	6	15	13	8	8	11	8	7	5	14	6	7	5	
Yel.-Green...	18	10	9	14	12	8	7	6	6	8	8	8	8	10	7	4	9	7	8	10	13	9	11	12	
Blue-Green .	15	10	12	15	19	11	12	9	15	6	7	12	14	16	10	6	12	18	14	12	13	14	26	23	
Blue	6	2	5	7	10	14	6	13	8	6	6	8	5	18	13	4	4	2	5	6	1	10	8	5	
Violet	1	1	0	5	9	10	7	7	12	7	14	10	11	18	10	7	1	4	2	4	6	6	4	7	
Purple	0	0	0	2	9	3	5	6	7	9	9	14	15	26	22	11	7	5	3	6	8	2	4	4	

TABLE XXIII.

SHADES CONST., TINTS VAR.

PLEASANT.

Shades.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	Tints.
Red	34	26	31	33	45	43	44	37	47	50	56	55	61	56	26	22	17	13	14	10	13	13	14	20	
Orange	28	26	35	29	43	56	43	40	36	39	51	64	52	43	26	27	21	28	22	14	22	22	25	30	
Yellow	40	46	50	44	44	49	49	52	51	37	53	60	63	56	40	41	41	40	37	33	31	36	42	42	
Yel.-Green ..	65	61	56	60	70	70	58	66	71	75	80	78	76	57	45	50	52	53	53	54	53	57	56	53	
Blue-Green .	32	31	30	36	49	54	51	49	54	56	67	66	75	68	59	66	42	38	40	37	42	41	41	48	
Blue	23	19	25	29	34	43	39	35	50	54	57	58	50	47	48	47	55	53	46	24	13	18	23	24	
Violet	24	16	23	25	29	37	24	33	39	40	46	46	43	33	27	33	28	33	40	38	30	29	28	24	
Purple	31	25	16	23	39	48	45	42	42	49	57	59	63	48	25	18	12	13	16	14	21	18	18	25	

TABLE XXIV.

SHADES CONST., TINTS VAR.

MOST PLEASANT.

Shades.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	Tints.
Red	7	9	7	11	14	6	5	9	10	13	19	16	11	20	5	5	1	1	2	1	3	5	7	4	
Orange	6	7	7	10	13	13	7	14	10	15	17	19	8	11	2	5	2	2	1	1	2	3	5	2	
Yellow	9	18	13	4	7	8	12	11	13	9	12	13	10	7	12	10	6	7	3	8	11	12	17	12	
Yel.-Green ..	19	27	18	28	20	19	20	19	21	22	29	34	25	15	13	12	15	18	17	20	22	20	29	27	
Blue-Green .	8	10	7	4	7	8	8	8	9	10	16	21	29	23	14	25	10	8	9	9	10	8	12	17	
Blue	5	8	6	6	11	9	7	3	3	6	13	14	12	10	10	12	10	13	15	5	4	4	5	5	
Violet	4	8	6	0	4	2	0	6	6	8	15	9	16	5	4	10	3	7	10	10	10	9	7	4	
Purple	10	6	7	7	10	7	4	6	4	14	16	17	21	14	5	3	4	1	3	4	6	6	2	2	

NOTE.—These two Tables were taken from the horizontal columns in Tables XVII, XVIII.

TABLE XXV.

TINTS CONST., SHADES VAR.

PLEASANT.

Tints.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	Shades.
Red	36	29	26	22	34	33	44	40	52	55	63	64	49	28	16	24	21	22	25	21	17	14	30	28	
Orange	51	45	25	38	44	46	48	44	45	65	64	71	66	45	28	41	32	33	32	34	25	29	38	43	
Yellow	45	45	38	28	47	44	50	55	47	63	61	71	63	54	37	50	36	38	32	36	28	38	44	47	
Yel.-Green ..	56	57	48	47	59	48	53	50	47	61	84	88	81	62	46	49	60	60	53	42	37	50	54	61	
Blue-Green .	48	55	40	39	44	38	60	50	49	32	64	82	75	70	57	52	51	42	41	31	31	36	49	51	
Blue	16	20	16	22	24	30	45	38	39	44	49	62	60	44	42	47	55	53	48	26	20	12	16	15	
Violet	12	10	15	19	17	22	30	32	39	45	55	60	51	43	25	28	22	33	45	34	29	22	14	15	
Purple	23	13	11	23	22	32	37	39	44	46	62	58	57	47	26	19	16	30	24	33	24	22	18	21	

TABLE XXVI.

TINTS CONST., SHADES VAR.

MOST PLEASANT.

Tints.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	Shades.
Red	12	5	6	3	6	11	13	13	14	17	22	25	15	6	4	7	9	3	6	6	6	2	9	12	
Orange	21	7	3	6	15	15	7	2	10	23	20	24	9	5	5	8	11	7	2	3	1	5	9	10	
Yellow	11	7	6	8	15	8	13	13	10	21	18	21	9	7	9	4	4	5	5	4	3	4	5	5	
Yel.-Green ..	16	18	14	13	18	20	11	13	10	18	40	27	22	13	12	9	14	10	11	9	12	15	18	14	
Blue-Green .	14	13	9	6	9	6	6	8	15	5	19	29	22	27	17	12	14	6	8	7	10	12	18	10	
Blue	3	3	1	2	3	4	5	9	9	6	20	19	21	12	10	10	12	13	10	8	2	4	3	1	
Violet	4	1	1	2	0	2	4	4	14	18	16	25	15	6	7	6	11	8	14	12	4	6	4	2	
Purple	5	4	7	2	5	3	13	12	16	23	29	24	20	12	5	4	6	4	4	8	8	5	2	3	

This may be seen at once upon a comparison of the single curves for the shades with shades with those for the tints with tints (which involves a transposition for a considerable difference of intensity). According to Purkinje's phenomenon the colour quality of the spectrum shifts with the change of intensity, i.e., with added intensity the colour quality moves toward the yellow pole of the spectrum, while with decreasing intensity the colour tone is altered in the direction of the blue. Let it be assumed that we have located the maximum of agreeableness for shade combinations. When the shades by the addition of intensity are transformed into tints, the colour quality is moved toward the warm end of the spectrum. We should, then, look for that same quality, having the maximum, at a point in the spectrum farther from the yellow pole. The consistency with which this phenomenon actually appears in our results is almost surprising.

If we inspect the 24 curves for shades (and their corresponding curves for the "most pleasant") and compare them with the similar curves for the tints, we find that the difference in the position of the maximum in the series is usually from 1 to 3 qualities, i.e. 1 to 3 twenty-fourths of the whole extension of the spectrum. (These curves, not here reproduced, are preserved in the Psychological Laboratory.)

In curves 1, 2 and 3 for the tints (that is, when tints 1, 2 and 3 are combined respectively with all the other tints) the maximum stands at 12, while in the shades it stands at 11, 10-12 and 12 respectively. It is even more marked in the next three curves, where for the tints the maximum is at 13, and in the shades is at 11, 11 and 10 (Figs. XXIII, XXIV). In curves 7, 8 and 9, which show the combining power of the yellows, since yellow is near the spectral pole, we should not look for so marked a change of position of the maximum, and as a matter of fact these curves in the tints form irregular plateaus with their highest points at 11, 13 and 12, while in the shades the more pronounced peaks have moved over to 11, 10, 11 (Figs. XXV, XXVI). Two of these curves (7, 9) also have minor projections in the red, which shift one colour in the direction opposite to that of the previous cases. But the apparently contradictory fact may be mentioned that in curve 8 this secondary

peak is shifted toward the blue. What incidental circumstance may have occasioned this slight variation in a minor elevation of the spectrum is not known; but, as in the whole field of the present observation this is the one exception to the strict obedience to Purkinje's law, we feel constrained to look for the reason in some accidental circumstance or association. In the yellow-green (curves 10, 11, 12) the plateaus continue to show little change at maxima; 11 obeys the law to the extent of 1 colour, the maximum falling in the shade at 2; while here the second prominence, indicating great pleasantness, lying in the yellow, remains unaltered. The curves for the blue-green and the blue are not high, the three for the former being irregular and having depressions at violet and orange: the three for the latter finding agreeable combinations in the yellow. In the curves for blue, the secondary elevations which stand in the red section in the shades stand at purple in the tints; while the yellow maxima in these curves would indicate that the "yellow pole" lies toward the yellow-green, as the movement is in that direction. (See p. 18 *infra,* and cf. Miss Baker's reference to "orange-yellow."*)

As we pass over into the violet section of the colour circle, while in the tints the greatest agreeableness is found between 16 and 14, indicating perhaps a slight tendency toward the blue-green, the maximum in the shades falls at 11, 10 and 9. This absence of a decided change we might anticipate from the fact that violet is not of great combining power, and also because it approaches the spectral pole. But perhaps a better interpretation of these diagrams would be to take the exceptional projections in the yellow sections of the curves for violet tints, which have nothing analogous in the shades, as a record of the peculiar affinity of violet and yellow in the tints. This is shown by a decided depression in the latter. Such being the case, the remaining portion of the tint-curves, compared with those of the corresponding shades, strikingly corroborates the law. As to the purples, the representative maxima are 9, 10, 15: 14; and 11, 13 in the tints: and 10, 11, 13; 11; and 11 (Figs. XXVII, XXVIII) in the shades, which seems to strengthen the

* University of Toronto Studies, Psych. Series, Vol. I, No. 4, p. 37 [213].

testimony of the preceding curves. A comparison of the curve showing the total number of selections for each shade (Fig. LXV) with that exhibiting the tints similarly (Fig. LXVI) upholds the verdict of the individual curves, as the maximum of the former is at 10, of the latter at 11.

When we enter upon an examination of the shades combined with the tints, and the tints with the shades, in reference to this question, it is well to superpose the curves; thus in Fig. XXIX curves for red 1 are reproduced. Here the plain curve shows shade 1 combined with the tints, while the dotted line indicates the combining power of tint 1 with the shades. (See also Figs. LVII to LXIV.) Through this whole series of 24 figures we observe a remarkable consistency as to the relative position of the maxima for the shades and for the tints. The fact that the maxima in the curves representing the shades as the constants invariably fall to the right of the maxima of the curves which represent the tints as the constants (before we pass the violet-blue pole) would lead us to ask the question, whether a difference of intensity be not the influencing factor as seen in the curves for the shades with shades and the tints with tints. But in this case at first glance there seems to be a consistent movement in the opposite direction to that observed in the other series. Before, however, we can accept this as a correct statement it is necessary to inquire where the change of intensity really appears, when shades are combined with tints and vice versa. If, when the shades are constant and the tints variable, we look for the maximum of pleasantness nearer the yellow-green, i.e. to the left of the maximum in the series in which the tints are constant, we are assuming that the intensity of the combinations in the former series is less than that in the latter. But, since in the former the shades are the constants, Purkinje's law would only be operative with reference to the variables which for each exhibition of the combinations display the spectral qualities, and therefore the shifting of the colour-quality in relation to the change of intensity is observable only with reference to the variables. Hence the maximum in the curves for the shades with the tints (e.g. the curves for red) falls to the right of the maximum of the curves representing the tints with the shades; for the variables (the tints) in the former, being of greater intensity than the variables

of the latter (the shades), have their corresponding colour-quality at any particular point of the colour circle nearer the violet-blue pole. Thus it is seen that the apparent contradiction is rather a consistency and contributes one of the most interesting evidences of the law. As we survey the series of curves indicating the selections of pleasant combinations of the shades with the tints, and vice versa, we observe that in curve 1, where the shade is the constant, the maximum lies one degree to the left of the maximum for the constant tint. This is also true with the curve representing the other two reds. The position of the maxima for the 6 curves in the orange and yellow assumes a similar position. As in the former experiments we found that the maxima in the curves for polar yellow-green, which fall in the green, show little inclination to alter with the change of intensity, so here the greatest pleasantness of the combinations with the shades as constants coincides with that where the tints are constant. While the general outlines of the blue-greens are in harmony with the observations in reference to the law under examination, there are some irregularities of detail which might be accounted for by the fact that in the Prang system of colours there is a certain compression of qualities between the poles through green and blue as compared with the greater distance round the colour circle the other way—from pole to pole through the orange.* In the blue, the movement with the change of intensity is clearly indicated in the outlines, even to details, until the maxima are reached, which serves to show the greenish-yellow, instead of the yellow (cf. p. 16 *supra*), to be the warm pole; and when the maxima pass the yellow-green we are not to be surprised, since the blue is near the polar colour, to see action due to contrast manifest itself in such peaks as the tall blue-green tint and yellow shade in blue 16. This preference, overshadowing the shifting of quality with change of intensity, is also seen in the two blue curves, though to a small extent (cf. p. 15 *supra*).

The last six diagrams in the series definitely give the testimony of the violet and the purple to the phenomenon under examination, and also corroborate the conclusion that the poles lie not at yellow and blue but a little to the right of each.

To sum up regarding this series of curves, it may be stated

* *Vide* University of Toronto Studies, Psych. Series, Vol. I, No. 4, p. 67 [243]

that the peaks of greatest pleasantness shift their position on the colour circle in the direction from the blue-violet towards the greenish-yellow or vice versa, as the intensity of the combination is varied (though on account of the greater distances between the poles on the side through the red, in the Prang system of colour qualities, the phenomenon is at this side more easily observed).

The series recorded previously, which have to do with the colours in relation to the tints and the shades, upon examination will be found also to verify the statement with reference to the shades and the tints with themselves.* What was said above regarding shades with tints and vice versa, with reference to the variables changing the position of the maximum with their change of intensity, also applies to this series. Since the variation of quality, intensity, or any other factor may result in a marked change in the agreeableness of combinations, which we should by no means seek to account for by Purkinje's phenomenon, we may not look for our curves to be similar throughout. In so far as any change of quality or intensity in the experiments is greater than that induced by the said phenomenon, just so far we must not be surprised to find wide differences in the pleasantness of the series. Hence the remarkable feature of all these curves is not that their points of greatest agreeableness lie in different regions of the spectrum and rise to different altitudes, but rather that notwithstanding this fact there is such a noticeable persistency in the relative position of the peaks. For example,† while the curves in Fig. XIII bear scarcely any similarity in general outline to those of Fig. XIV, because the tints find their most harmonious partners among the blue-green colours, whilst the shades in that quarter are least agreeable, yet we notice the decided tendency of the plain curve in the former (where the tints are the variables) to fall, in relation to the dotted curve, nearer the violet-blue pole, particularly in the red and yellow-green sections, and the curve (plain) in the latter, in which the shades are variables, indicates in general outline a preference for the yellow, e.g. decidedly in green and

* *Vide* University of Toronto Studies, Psych. Series, Vol. II, No. 3, pp. 1-20 [165-184].

† Ibid.

purple; and as to a comparison of the former with the latter, it will be observed that without exception the region of greatest pleasantness with the tints as variables is farther from the "warm" colours than that in the shade curves. These observations are justified by an inspection of the summation curves (Figs. XXI, XXII), where the maximum of the combined shades and colours is at the yellow pole, while the corresponding elevation in the tints stands nearer the blue section, viz. in the green. The plain curve in Fig. XXI, in common with the dotted one, has a peak at yellow, while the maximum in the one moves to the blue-green, leaving that in the other at greenish-yellow. The relation between the two lines in Fig. XXII is inversely similar—also noticeable in the green section. If it is desired to trace the phenomenon through the fourteen figures similar to XIII and XIV it will be found that what has been said holds generally: in Figs. V to X quite regularly; also in XII, XIV, XVI; and in XVII most remarkably. But in the green tint-curves (XI, XIII) there is one quality which is so decidedly partial to its own colour that it presents a striking feature at this part, while the rest of the outline indicates the usual change. As to the violet shades (XVIII), in their choice of the violet itself the position of these secondary peaks may be accounted for by the fact that the quality is already so near the pole, that the difference of intensity in the two curves is overshadowed by the preference for other contrasts. This may also be taken as a further evidence of the violet approximating the polar colour. (*Vide* pp. 15, 17, 18 *supra.*) The purple, also a difficult colour to match, offers some variation, for while in tints with colours the ends (red and purple) of the spectrum are exceptional (Fig. XIX), yet in Fig. XX it is the centre (green), which indicates such a peculiarly decided selection, in the yellow-green shades with the colours.

Further confirmation of the observation in reference to shifting of the point of maximum pleasantness due to change of intensity, is found in the curves for complementarism (XXXI to XXXIX). In the curve for shades the line passes the abscissa between 9 and 10; in that for the tints it is between 10 and 11; while at the purple section a corresponding movement is seen in the tints toward the blue. In the curve for colours

with themselves there is a peculiar change in reference to the yellow, which has its point of greatest pleasantness on the violet side of the blue, whereas in the former curves (shades and tints) the maxima are at yellow-green (and red). The reason for this is not evident, though a comparison of Baker's curves for yellow with Figs. XLV and XLVI below will show that in the latter there is a minor projection in the violet-blue, and in the former there are high prominences in yellow-green and red.

As an introduction to the remarks on complementarism with which the following pages are concerned, a survey of Figs. XXXI to XXXIX will be to good purpose. These diagrams show the relative position of the maxima and the complementaries in each of the series which we have examined. The abscissa-line shows the complementaries, while the curves represent the distances at which the maxima lie from them. The abscissæ and ordinates are drawn on the same scale. The maxima lying to the left of the complementaries are drawn above the abscissa-axis, while those to the right are shown below it. Thus the greatest contrast would be exhibited by the curve falling upon the complementary line, while the highest or lowest peaks show the small contrasts. Fig. XXXI is drawn from an examination of Baker's curves for colours combined with colours, while Figs. XXXII and XXXIII are taken from the present work, tints with tints and shades with shades. In XXXIV and XXXV a similar exhibition is given in reference to the shades with the tints and tints with the shades, while XXXVI, XXXVII, XXXVIII and XXXIX deal with the possible combinations of colours with shades and with tints.

The examination of these figures in reference to complementarism leads to a discussion of some of the rules laid down provisionally by Professor Kirschmann.* Most of these propositions, in so far as our experiments are relevant to them, seem to be verified by our results; though more definite statements may be possible upon examination of the diagrams, where it may be seen that some of the rules have application only to a restricted area of the spectrum. For instance, a survey of the curves

*Kirschmann, *On the Aesthetic Significance of Light and Colour Contrast* (Philos. Studien, Vol. VII, p. 391). For statement of rules see Baker, *Experiments on the Aesthetic of Light and Colour* (University of Toronto Studies, Psych. Ser. Vol. I, No. 4, p. 39 [215], foot-note.

representing the relation of the complementary to the maxin indicates that his first rule, viz. "Our sense of sight seems find pleasure in combination (of two components) with a max mum, or at least a great, contrast effect," applies particularly the terminal parts of the spectrum (blue, violet, purple, re orange). It is interesting to note that, while in those diagram which represent an intensity and a saturation contrast as we as a colour contrast (T. S., S. T., C. T., T. C., C. S., S. C.*) there is a preference for less contrast of quality—the quality contrast being replaced by contrast of intensity and of saturation, in those diagrams (S. S., T. T., C. C.) in which a contrast i confined to that of quality—except in so far as there is a differ ence of intensity in the same saturation, e.g. between yellow an blue (*vide infra*, p. 25)—there is a uniformity in the three curve which indicates a choice of wide colour contrast, except in th yellow and green with their adjacent colours, where there is con trast of intensity and quality but not of saturation. The blues violets and purples make pleasant combinations with qualitie but slightly removed from the complementary. In the case o the shades and the tints, each with themselves, the maxima i the orange and yellow fall to the left of the complementaries i.e. in the greens (see Figs. XXIII, XXIV), while the maxima i the greens lie to the right, i.e. in the reds (see Figs. XXV XXVI). This means that while the complementaries in these cases lie near the blue pole (at blue and violet-purple respectively) the maxima are in the greens and reds. Further indisputable evi dence of the rule that "intensity contrast may replace that o quality" is offered by Fig. XL, showing intensity contras in the same quality. The curves are drawn from the diagona columns of numbers in the tables combined to give Tables xvii xviii. The plain curve stands for the combination of the shades with tints of their own quality; the dotted line vice versa, viz tints constant and shades variable.

Kirschmann's rule 7, according to which the dogmatic state ment that certain colours will not combine with certain othe colours is unverified, is corroborated by our experiments; fo

* T_2 and S_2 in the previous article are synonymous with T and S in this one, a T_1 and S_1 were not used.

while our 2,556 different combinations are very far from exhausting the possible number, intensity saturation, colour-quality and shape being considered, yet there is scarcely a combination of two qualities which under some conditions has not been many times chosen as agreeable.

The remark in rule 4 that "combinations of different saturation degrees (practically shades and tints) of the same colour or of very similar colours are also found to be pleasant," is strikingly verified by a survey of Tables xvii, xviii, and Fig. XL, and especially in the case of the yellow-green, blue-green and blue, which find even their maximum pleasantness in their own qualities (that is, within 1-24th of the colour circle).

Rule 8 states that "colours of high saturation and of equal brightness when combined do not make combinations of marked agreeableness." If we compare the experiments performed by Baker, when colours of high saturation and of approximately equal brightness were used, with those of the other series discussed in this article, it will be found that while the average number of selections of the "pleasant" made by each observer for all the colours (with themselves) is $\frac{10742}{30} = 358.2$,* the other series are:

$$\text{S.S.} \quad \frac{6132}{23} = 266.6$$

$$\left.\begin{matrix}\text{S. C.}\\ \text{C. S.}\end{matrix}\right\} \quad \frac{3905}{10} = 390.5$$

$$\left.\begin{matrix}\text{T. S.}\\ \text{S. T.}\end{matrix}\right\} \quad \frac{7769}{23} = 337.7$$

$$\left.\begin{matrix}\text{C. T.}\\ \text{T. C.}\end{matrix}\right\} \quad \frac{3532}{10} = 353.2$$

$$\text{T.T.} \quad \frac{6694}{23} = 291.0$$

But since in the series C. C., S. S., T. T., there is one combination less (each colour with itself) than in the others, an exact comparison would give the following:

* University of Toronto Studies, Psych. Series, Vol. I, No. 4, p. 47 [223].

$$\text{S.S.} \quad \frac{266.6}{23} = 11.59$$

$$\left.\begin{matrix}\text{S. C.}\\ \text{C. S.}\end{matrix}\right\} \quad \frac{390.5}{24} = 16.27$$

$$\left.\begin{matrix}\text{T. S.}\\ \text{S. T.}\end{matrix}\right\} \quad \frac{337.7}{24} = 14.07$$

$$\left.\begin{matrix}\text{C. T.}\\ \text{T. C.}\end{matrix}\right\} \quad \frac{353.2}{24} = 14.71$$

$$\text{T.T.} \quad \frac{291.0}{23} = 12.65$$

$$\text{C.C.} \quad \frac{358.2}{23} = 15.57$$

These figures lead us to the conclusion that colours of equal intensity and of high saturation do make combinations of marked agreeableness, far surpassing combinations of either less or greater intensity and of less saturation, when the components are of equal intensity (i.e. shades with shades and tints with tints), and of the others being only slightly excelled by the colours when combined with the shades.

But it must not be forgotten that the best saturation in the Prang system is far from being a full saturation, as can easily be seen by comparing the Prang system, as it was used in our trials, under ordinary illumination, with the same Prang colours illuminated with proper colour-filters. Further, the fact that the different colour-qualities in the same series (in the Prang system) differ in intensity is a matter for consideration. For instance, the yellow is much brighter than the blue. So that to say that the above figures for the colour series, in comparison with the other series, give us an exact indication as to how far "colours of high saturation and of equal brightness" do make combinations of marked agreeableness would need to be qualified by the condition of the diversity of intensity within each series, especially since a survey of the curves for this series (see Baker's article) will show that the most decided prominences fall where this intensity contrast would be the greatest, which fact is especially conspicuous in curves for red, blue, violet and purple.

This leads to a consideration of von Bezold's and Kirschmann's proposition that "it is not in the combination of comple-

mentary colours that we have the most harmonious effects;"* for our diagrams throughout the different series give positive evidence in this direction. There is, however, one case that needs consideration. A glance at the curves in the three series, colours, tints, shades, each with themselves, shows that the maxima in the curves for blue fall at or very near the complementary (also shown in curves XXXI, XXXII, XXXIII). But while at this point we find the greatest intensity difference within each series, it seems reasonable to suppose that had not the light contrast helped to fix the maxima at this point they would have fallen at a short distance on either side of the complementary. This surmise is verified by a survey of the curves showing the relation of the complementary and the maxima when there is a difference of intensity between the series (Figs. XXXIV to XXXIX). Consulting these curves, let us examine the yellow quality in diminished intensity (in a shade series) combined with a blue of higher intensity (either a saturated or a tint series), thus partially eliminating the intensity contrast between the yellow and the blue in the series of equal saturation. If what has been said above be correct we should expect the maxima to fall some distance from the complementary; which is seen to be the case in curves XXXIV, XXXVII, XXXVIII (cf. also Figs. LIX, LXII). The same will be observed also in those series in which the intensity of the yellow is increased or that of the blue diminished, i.e. in those where the blue in the shade is compared with the yellow of the saturated colour or its tint. The intensity contrast in this case is increased beyond that found between the two colours in the same series (see Figs. XXXV, XXXVI, XXXIX). In this case the increase of intensity in the yellow and the decrease of intensity in the blue, through the intensity contrast, decreases the saturation in both cases, the one (tint) towards the bright grey, and the other (shade) towards the corresponding dark grey.†

There is also to be considered the change of quality according to Purkinje's phenomenon, induced by the intensity difference, though in this case it will be so small that its effect may not be

* University of Toronto Studies. Psych. Series, I. 215. See also Dobbie, *Experiments with School Children on Colour Combinations.* (Ibid. I. 251.)

† Cf. Kirschmann's discussions of the Colour-cone in Am. Jour. of Psych., VII. 394, and in Archiv für die gesamte Psychologie, VI, 407.

noticed. It has been suggested that the contrast of quality might be observed to intensify the saturation of the components, or at least to nullify the contrary effect of the intensity increase. But the slightly exaggerated condition of contrast exhibited in the following experiment where the saturated colours are used will serve to show conclusively that the effect of decreasing saturation by intensity increase far exceeds the opposite tendency of quality contrast with these particular colours. On a saturated blue field, 6 inches by 3 inches, place two isosceles triangles of a saturated yellow, their bases coinciding with one end of the blue field, and their apices falling at the other extremity. Between them a triangle is formed of the blue. The phenomenon is well observed if one stand at a distance of 10 feet from the figure. From such an experiment it will be seen that the narrow portion of the blue has become darker and less blue, and that the corresponding portions of the triangles of the complementary colour are brighter and less yellow.

Figs. XLI to LVI are curves (tints with tints, and shades with shades) drawn from the average of the three horizontal columns whose totals are seen in Tables xix to xxvi. Thus it is seen that Fig. XLI represents the power of agreeable combination of the colour red (no. 2) in company with 1 and 3. Here the unmistakable pleasantness in the combination of red and green in the tints and in the shades corresponds to the result obtained in the former experiments with the tints and the colours, and shows virtually no change from the curves representing each of the three reds. Orange also combines most pleasantly with the greens, but the peaks are not so marked as in the curves for red, while there is also a secondary prominence indicating some agreeableness in its combination with the red. The yellow is more indifferent in its pleasantness of combination, for, as in the case of the colours with the tints and the shades, the curves extend irregularly over the whole field, with a preference for yellow-green and red. The curves have no high peaks. Nevertheless they cover a larger surface, that is, although the preference for certain colours is not so pronounced the general agreeableness is greater. At a considerable elevation the indication of the power of agreeable combination with a wide range of other colour qualities is in direct contradiction to the above men-

tioned statement of aversion to yellow and a further confirmation of Baker's results in reference to the same question.*

More general and more conclusive results may be found in an examination of the Summation Tables. In colours with themselves yellow stands without a peer (Baker's Combination Curve XXXVII). Külpe, in reporting upon Baker's results, uses the word "yellow-green."† Since we are in this article dealing with a greater variety of combinations, in which the maxima move into the green, we may mention that Baker's maximal points for the pleasant fall in the orange-yellow and green-yellow, at 8 and 10 (see Tables ii, iii, the 8 being only 1-559th higher than the 10), while the most pleasant maximum is at yellow 9. When colours are combined with tints it is only inferior to green (yellow-green numbers 11 and 13, Tables i, ii; see also Table ix); and in colours and shades yellow predominates (Table xi and Tables iii, iv indicate the yellow toward the orange, 6, 7). Though in the four series in which shades and tints are judged the greens stand highest (at 11, 12; see Tables xiii to xviii), yellow is the next highly favoured (see also Tables xxvii to xxxii *infra*). These conclusions are less liable to the criticism of limitation, since they rest upon 2,556 different combinations, quality, saturation and intensity being varied. Upon these combinations, reckoning the "most pleasant" judgments to duplicate the number, and remembering that the colour series was repeated, there were 216,092 judgments made, of which 39,995 were recorded as choices (pleasant or most pleasant).

It is important to compare these results with those of Miss Chown's investigation with greys and colours, where yellow and green are decidedly in the minimum. With the question as to why this difference should be found Miss Chown has dealt carefully. She says, "Perhaps yellow and green are preferable in combination with other colours because they are most indifferent, emotionally, thus furnishing in such combination a considerable contrast with regard to hedonic tone. This same quality of comparative indifference makes them least apt when combined with indifferent grey because there is not enough variety in the

* Op. cit., pp. 53 and 72.
† *Bericht über den II. Kongress für experimentelle Psychologie*, p. 28.

hedonic tone."* If, however, this be the explanation it may be difficult to account for the fact that in the results with colours, shades and tints, these qualities "emotionally indifferent" form highly pleasant combinations among themselves (see Baker's curves for green and yellow; colours with tints and shades, Tables ix to xii; and the summation curves below). But again, the intensity contrast may account for this.

Turning to the description of the figures in hand, we find that curves for yellow-green and blue-green are similar to those for yellow, except that in the yellow-green curves the preference for the yellow-green has moved towards the yellow, and in the shades the selection of the red is more pronounced. A very noticeable feature in the curves for blue is the fact that they are very inharmonious with the violet. In the curves for violet the maximum falls in the yellow-green. It may be noted that the violet, as observed when the full saturation is used with tints and shades, is here also an exclusive colour. Purple combines very well with yellow-green, and in the tints with the tints also exhibits a tendency to combine with the orange.

	Shades With Shades.	Harmonize Best With	Harmonize With	Do Not Harmonize With
1	R.	YG.	(R.)	V. P. OR. B.
2	O.	YG.	O.	V. P. B. O.Y.
3	Y.	YG. and BG. R.	B. (P.)	V. Y.
4	YG.	R.	B. Y. (9) BG.	V.
5	BG.	R. Y.(9) YG. (11).	BG.	V.
6	B.	Y. (9) G.	R.	V. P. O.
7	V.	YG. Y. (9).	BG. (13) R. O. (6).	B. V. P.O. (4).
8	P.	YG. BG. (13).	R. (1).	P. R. (3) O. V. B.

	Tints With Tints.	Harmonize Best With	Harmonize With	Do Not Harmonize With
1	R.	YG.	O. Y.	P. V. B. R.
2	O.	G. (YG. and BG.).	R. (V.)	P. B. O.
3	Y.	G. R.	B. V.	Y. P.
4	YG.	R.	V. O.	YG. B. (16).
5	BG.	P. O. Y.	B. V. (21)	BG. V. (19).
6	B.	Y.	G. (12, 14).	B. V. P. (22) R.
7	V.	Y. YG. (BG. 13, 14).	P.	R. B. V.
8	P.	BG. YG. O. (4).	Y. (V.)	R. P.

* University of Toronto Studies, Psych. Series, Vol. II, No. 2, p. 12 [94].

Having already considered these series, in which the shades are combined as constants with the tints, and the tints in combination with the shades, in reference to the question of Purkinje's law, let us now inspect the same diagrams with reference to their ability to form agreeable combinations with one another. Viewing the curves which represent each shade (three divisions to a shade) with the tints as variables, we see that red harmonizes best with the green, and very well with the orange and the yellowish-orange, but will not be found pleasant when placed beside violet, blue or purple. The next spectral quality, orange, finds its most harmonious combination in the green (12), makes a fair combination with itself (6), but will not harmonize with the violet, blue and purple, nor with the red. Shade yellow matches with the green tints (12, 13, 14), very well with the red, orange and yellow, but it does not combine well with the violet.* This is also true when the tint is the constant and the shade is the variable. Comparing the table on page 14 of the paper on colours with tints and shades, where the tints of yellow-green combine best with themselves, we are not surprised that in this case also, when the shades and tints of the same quality are used, they find their most pleasant combinations among themselves, go very well with the orange, and do not combine with the blue-green. While the blue-green in full saturation goes well with the red and with itself, when used as a shade with a tint it combines well with itself but will not harmonize with the red; and when a tint with a shade it is not pleasant in combination with the violet, and is very decided in its selection among the qualities of yellow-green, having its maximum at 12 and an "unpleasant" depression at yellow-green no. 10 (Fig. LXI. The blue in this series, like that in the colours with the shades and tints, shows a very high degree of pleasantness in combination with itself, but in this case has its maximum at the yellow-green. As to the violet, which has always been found difficult to suit, we find that it goes fairly well with itself and with orange, but best with the yellow-green (11, 12). This is also true when the tint is the constant and the shade variable. In both cases, as also in the tints with the saturated colours, it cannot be combined with red. There seems to be

* Cf. University of Toronto Studies, Psych. Series, II. 178.

consistency here with our previous results in regard to the purple; for the green and yellow with their nearest neighbours are its most friendly companions, while dislike usually accompanies its combination with violet, red or blue.

	Shades With Tints.	Harmonize Best With	Harmonize With	Do Not Harmonize With
1.1	R.	BG. YG. (not 10)....	O. Y. (7)	V. B. P.
2.	O.	G. (12)	O. (6).....	V. B. P. R.
3.	Y.	G. (12, 13, 14)	R. O. Y.....	V.
4.	YG.	YG.	O.	BG. (15).
5.	BG.	G. (13)	B.	R.
6.	B.	YG. B.....	O. (6).....	V. R.
7.	V.	YG. (11, 12).....	V. (19, 20) O. (6)	B. (8).
8.	P.....	G. (11-13).....	OY. (6, 7) R. (1)	B. V. P. R. (3).

	Tints With Shades.	Harmonize Best With	Harmonize With	Do Not Harmonize With
1	R.....	YG.....	Y. R.....	V. B. P.
2	O.....	YG.....	R.....	V. R. B.
3	Y.....	BG.....	YG. P. R. O. Y. (not 7 YO.)...	V.O. (4).
4	YG.	YG.....	B. P. O.....	V.
5	BG.....	YG. (12).....	BG. Y.R. (R. P.)	V. O. YG. (10).
6	B.....	G. (12, 13) B.....	Y. (7).....	V. P. R.
7	V.....	YG. (12).....	V. (19).....	R. O. B.
8	P.....	G. (11-13).....	Y. (V.).....	B. R.

As curves for three qualities added together have been made, giving the above results, it would be well to represent by diagrams the total* power of harmonious combination of each shade with all the other shades, each tint with all the tints, and similarly the series S. T. and T. S. Figs LXV to LXVIII are drawn from the totals in Tables xiii to xviii, and hence exhibit the relative agreeableness of each quality when passed through the whole series. For instance, Fig. LXV, displaying the shades, verifies in a general way what the particular curves showed in detail, viz. that yellow-green under these conditions is the most highly agreeable, while there is also considerable pleasantness in the red-purple section. The next figure

* "Total" curves of this paper correspond to "summation" curves of the previous one, while the curves representing Tables xxvii to xxxii of this paper are called "summation curves."

gives us similar results with the tints, though with the orange and yellow sections of the curve raised to a greater height. The remaining two curves for S. T. and T. S. respectively follow the same outline, with, however, the secondary peak at orange. These four curves harmonize well with those of the other series* and with the summation curves in the series given below.

Following the plan of more perspicuously representing final results by tables showing the power of aesthetic combination of each colour with the shades and with the tints, we reproduce in Tables xxvii, xxix, xxxi the totals of pleasant combinations, while Tables xxviii, xxx, xxxii give the same for the most pleasant. In order that its position may be easily located in relation to the maxima the complementary is marked with × for shades with tints, and with + for tints with shades. Tables xxvii and xxviii deal with the shades when combined with themselves, and enable us to see at a glance the comparative agreeableness of each shade. Thus it is easily observed that the violet shade is not generally acceptable in combination with other shades, and that it is relatively most agreeable when combined with the yellow-green. It is also noticeable that the yellow-green presents the greatest number of pleasant combinations and is found to be most pleasant when combined with the red. Tables xxix and xxx give a convenient survey of the field in the tints, where a similar observation as to violet may be made. A comparison of Tables xxvii and xxix with Tables ix and xi shows that while in the combinations of the colours with the tints and shades† there is a greater number of pleasant selections with the shades, for the combinations of shades and tints each with themselves the tints have the advantage to the extent of 562; that is, the total number of "pleasant" selections for the shades is 6,132, whilst that for the tints is 6,694.

Tables xxxi and xxxii report in the same manner the total results of the shades in combination with the tints. Each horizontal column shows the pleasantness of a shade combined with the spectral qualities in tints. Thus the first column exhibits the red. When combined with the tints, red has a greater affinity for itself than for blue, violet or purple, but it

* Cf. Baker, op. cit., Combination Curve, Fig. XXXVIII, and Figs. XXI, XXII, of University of Toronto Studies, Psych. Series, Vol. II, No. 3.

† University of Toronto Studies, Psych. Series II. 183-184.

is inferior to the orange-yellow and the greens, its greatest pleasantness appearing in yellow-green. As a matter of fact, the only exception in this series is that of the blue-green, the maximum being with another saturation of its own colour. To the fact of yellow-green and blue-green being most harmoniously combined with themselves there is no analogy in the experiments in the colours with the tints and shades, nor in those of the tints and shades each with themselves. In every-day life, greens of different intensity and saturation occur frequently side by side, as in exterior and interior house decoration and in costumes.

Each perpendicular column records the number of judgments in favour of a tint as constant with the shades as variables. For instance, although when the violet is a shade we find the number of judgments in favour of its combination with yellow-green to be 132, yet we see its aesthetic value increases almost 25 per cent. (to 160) when it is used as a tint with the shades. It is even more pronounced in the "most pleasant" Table xxxii. When saturated colours in combination with shades were under consideration we found that orange and yellow had the preference, and when colours were combined with tints the greatest agreeableness was at blue-green and violet. But at present, when we combine shades and tints with one another, we find the maxima at yellow, yellow-green and blue-green. The orange shade agrees to some extent with its own tint, but appears best in company with the yellow-green. A similar statement may be made regarding the violet and the blue. The purple has the maximum at the yellow-green, while it does not harmonize with itself. No comparison of these cases in which the qualities combine well with themselves can be made with the corresponding totals in Tables xxvii to xxx, because in Tables xiii to xvi, from which they were taken, the numbers which represent identical qualities were ignored, on account of the same colour in the same intensity not forming a binary combination.

These tables have been diagrammatically represented in Figs. LXIX to XCII, where the movement of the maxima and the relative aesthetic values of qualities may be more easily followed. The S. S. curves are drawn from Tables xxvii and xxviii, the T. T. figures from xxix and xxx. The remaining curves

(LXXXV to XCII), taken from Tables xxi and xxxii, exhibit the S. T. and T. S. series. The plain curves, showing the shades as constants, correspond to the horizontal columns of the tables, while the dotted lines for the shades as variables are taken from the perpendicular columns.

TABLE XXVII

SHADES

PLEASANT

Shades.	R.	O.	Y.	Y.G.	B.G.	B.	V.	P.	Shades
R	54	76	131	225	146 ×	74	56	48	810
O	76	74	87	170	104 ×	65	49	44	669
Y	131	87	66	167	140	116 × +	73	102	882
Y.G	225	170	167	118	142	146	102 +	155 ×	1225
B.G	146 +	104 +	140	142	80	112	63	109 + ×	896
B	74	65	116 + ×	146	112	34	28	53	628
V	56	49	73	102 ×	63	28	30	36	437
P	48	44	102	155 +	109 × +	53	36	38	585
									6132

TABLE XXVIII

SHADES

MOST PLEASANT

Shades.	R.	O.	Y.	Y.G.	B.G.	B.	V.	P.	Shade
R	8	15	29	73	51 ×	21	11	16	224
O.....	15	26	16	63	26 ×	10	10	8	174
Y.....	29	16	12	32	27	31 × +	21	27	195
Y.G.....	73	63	32	32	27	33	33 +	53 ×	346
B.G.....	51 +	26 +	27	27	12	23	17	30 + ×	213
B.....	21	10	31 + ×	33	23	6	5	5	134
V	11	10	21	33 ×	17	5	14	11	122
P	16	8	27	53 +	30 × ±	5	11	14	164
									157[illegible]

TABLE XXIX

TINTS

PLEASANT

Tints.	R	O.	Y.	Y.G.	B.G.	B.	V.	P.	Tints.
R	36	111	136	175	143 ×	73	40	15	729
O	111	56	106	156	159 ×	90	101	70	849
Y.....	136	106	64	140	151	135 × +	128	113	973
Y.G	175	156	140	90	122	119	140 +	133 ×	1075
B.G	143 +	159 +	151	122	88	126	123	141 + ×	1053
B	73	90	135 + ×	119	126	54	53	72	722
V	40	101	128	140 ×	123	53	34	58	677
P	15	70	113	133 +	141 × +	72	58	14	616
									6694

TABLE XXX

TINTS

MOST PLEASANT

Tints.	R.	O.	Y.	Y.G.	B.G.	B.	V.	P.	Tin
R	4	16	21	37	37 ×	13	2	0	13
O	16	12	19	34	45 ×	31	24	14	19
Y	21	19	18	19	36	27 × +	26	18	18
Y.G	37	34	19	24	25	20	31 +	32 ×	22
B.G	37 +	45 +	36	25	40	36	39	63 + ×	32
B	13	31	27 + ×	20	36	10	12	23	17
V	2	24	26	31 ×	39	12	12	17	16
P.....	0	14	18	32 +	63 × +	23	17	10	17
									156

TABLE XXXI

SHADES WITH TINTS

PLEASANT

Shades.	R.	O.	Y.	Y.G.	B.G.	B.	V.	P.	Tints.
R	91	121	128	161	143 ×	52	37	47	780
O	89	128	119	154	121 ×	76	58	77	822
Y	136	137	152	150	159	122 × +	101	120	1077
Y.G	182	200	195	233	178	155	160 +	166 ×	1469
B.G	93 +	139 +	154	189	202	146	119	130 + ×	1172
B	67	106	124 + ×	169	145	155	83	65	914
V.....	63	91	96	132 ×	103	94	108	81	768
P	72	110	129	165 +	136 × +	43	51	61	767
	793	1032	1097	1353	1187	843	717	747	7769

If read horizontally the Table shows S. constant, T. variable; if vertically, vicè versa.

TABLE XXXII

SHADES WITH TINTS

MOST PLEASANT

Shades.	R.	O.	Y.	Y.G.	B.G.	B.	V.	P.	Tints.
R	23	31	24	48	36 ×	7	6	16	191
O	20	36	31	51	21 ×	9	4	10	182
Y.....	40	19	35	34	29	23 × +	22	42	244
Y.G.....	64	67	60	85	53	45	59 +	76 ×	509
B.G	25 +	19 +	25	47	66	43	28	37 + ×	290
B.....	19	26	13 + ×	33	32	35	24	14	196
V	18	6	12	32 ×	25	20	30	20	163
P	23	24	14	47 +	40 × +	8	13	10	179
	232	228	215	377	302	190	186	224	1954

If read horizontally the Table shows S. constant, T. variable; if vertically vice versa.

We have already explained, when describing our method of experiment, that in the instructions to the observers it was emphatically stated to be essential to the success of the experiments that they should abstain from any association of the colours under examination with persons, things or events. It is needless to ask why a certain sensation or combination of sensations is accompanied by a certain aesthetic tone, for to attempt to answer this by stating that the feeling of like (or dislike) is associated with a sensation in another field would simply be to shift the problem from the first field to the second and then to be confronted by it in another form. If it be said that the reason one prefers the colour orange to that of violet

is that our ancestors found the fruit which bears the colour (and the name) pleasant to the taste, and that therefore one has evolved a liking for the colour, it is apparent that we have now the problem, Why did our parents like the fruit? The same difficulty in answering why one likes a colour presents itself as to why one likes a taste, therefore perhaps no one would be so unwise as to suggest that all preferences for certain colours have been similarly developed from some particular sensuous field; for it may be suggested that on the same ground our fore-parents' enjoyment of the violet-coloured plum would not have given them such a peculiarly restricted pleasure in the violet sensation. Further, the violet colour has another advocate in the sense of smell, gratified by the flower of the same name. If we are to trace the pleasure of one sense to that of another, why should not smell, which undoubtedly has played and does play such an important part in animal life, instead of taste be regarded as the original? And if, on the other hand, both taste and smell are responsible for the affective quality of the violet colour, with so much in its favour we should expect it to be less exclusive. It requires but slight thought on the question to see that it is often quite true that a pleasant sensation in one field is joined by nature to even an unpleasant one of some other sense. It has been said that ease in pronunciation is one formative factor in the development of language, while the selection of pleasant sounds, i.e. what is called "taste," is another. This means that the feeling-tone accompanying the sensations experienced in pronouncing certain syllables has its influence upon the second attempt to produce the same or a similar sound, and this in course of time produces by "natural selection" that sound with whose articulation there is associated the least disagreeable feeling (the greatest "ease"). As to "taste," a similar statement may be made. "Taste" is the affective tone accompanying the sensations heard, whether individual or in combination. Now, to explain "ease" in terms of "taste" (or vice versa), or to give one as a reason for the other, would only complicate the question. It is quite conceivable that the two should even be at variance, that is, that a word which is difficult to pronounce might be euphonious, or that one spoken with ease should be inharmonious, e.g. "onomatopoetic" and "disk,"

respectively. A similar difficulty confronts him who would say either that on account of unpleasant associations yellow is not pleasant, or that the pleasantness of orange is due to the fact that that colour happens to be the colour of the fruit. First, it is not only untrue that the golden sun is unpleasant, but also is it false to say that yellow as a component in combinations is not of great agreeableness. This is shown by experiment.* Second, who would assume that the orange colours, tints and shades as combined in the sunset derived their beauty from the eating of the orange? And again, if "the taste for colour . . . must all be originally referred to the habits of our frugivorous ancestors,"† how can the fact, demonstrated by our experiments, be explained, namely, that not the colours of ripened fruits, but the colour most frequently met with in nature —that of the foliage and unripe fruit (yellow-green)—stands highest in aesthetic value when shades and tints are used, as is strikingly indicated in the summation curves LXIX to XCII? These figures also show that the red (in combinations consisting of shades and tints) is most frequently selected, when combined with the green.

If pleasantness of a colour is to be accounted for by its prevalence, support may be found in the facts of nature. Though the persistence of a colour may become wearisome, when a limited period of time is considered, as when one continuously gazes at a particular colour-combination, yet it will be found that the common colours are generally acceptable. This is not so surprising in reference to colours when we remember that it also applies to other aspects of life. It is said that we like what we know best,—the familiar tunes, poems, scenes and people. The results of our experiments show that so far as the affective quality accompanying colour-combinations is concerned, the omnipresence of yellow-green in its various shades and tints in the foliage is most highly appreciated. The prevalence of yellow in the sun, the stars, and in the complexion of a great part of the human race is in harmony with the high degree of pleasantness of that colour-quality, while the incessant appear-

* *Vide* Baker, op. cit., Fig. XXXVII, combination curve for saturated colours, and University of Toronto Studies, Psych. Series II. 183-184, for colours with tints and with shades.

† Grant Allen, *The Colour Sense: Its origin and development*, p. 281.

ances of orange in the sunsets and in the ripened grain are universally agreeable. It is true, however, that any such comparisons involve not only quality of colour but an infinite variety of conditions of size, shape, background, intensity and saturation. It is interesting to observe the relation of agreeableness and frequency of occurrence not only of certain colours but of combinations of such colours as yellow and blue in the sky and stars, as red or orange of fruits and yellow-green of the leaves, for throughout the varied series of our experiments the great pleasantness of these combinations is evident. (See Tables ix to xii and xxvii to xxxii.)

While curves XXXI to XXXIX represent the relation of the maxima of pleasantness to the complementaries, it is yet desirable to combine these curves in such a way as to be able to compare the different series with regard to this relation, that is, we wish to view more perspicuously the changes in the maxima corresponding to the intensity changes through the five series from tints with themselves through C. T., T. C., C. C., C. S., S. C., to shades with themselves. In Figs. XCIII to CXVI each of the 24 curves shows one of the 24 colour-qualities, through the five series. The abscissa shows the point in the colour-manifoldness at which each maximum of the different series falls, while the ordinate shows the intensities. The perpendicular line cutting the curve represents the position of the complementary. The curve, therefore, not only exhibits the relative positions of the maxima in the different intensities, but also their relation to the complementary colour. High peaks not maxima are marked thus (×), whilst lesser prominences are marked thus (v).

(1) Curve XCIII shows us, in regard to red number 1, that the complementary falls in the blue-green toward the blue, and that the maxima in the five series are situated as follows: In the tints with themselves the maximum is at green; when the colours are combined with the tints it shifts toward the yellow-green with minor peaks in the adjacent qualities and in the purple or red. In the colours with themselves the maximum is again in the yellow-green shifted in the direction of the yellow. In the fourth series it stands in the yellow itself (with minor maxima in the green) indicating that the change of intensity

from series to series is compensated by the movement from the darker green to the lighter yellow, but the next move in the shades with themselves takes us back to our starting-point in the green. This compensation may be seen in the two following figures, which represent the reds of numbers 2 and 3.

(2) In the three curves for the orange the maxima of the first correspond very well with those in the curve for red, but there is an apparent change in the other two (Figs. XCVII, XCVIII). In the latter the finest combinations among the colours with themselves are found in the violet and purple, a tendency toward these colours being already indicated in Fig. XCVI. However, a glance at the original curves, in Baker's work, will show that there is not a great difference in height between the peaks for the violet and those for the yellow-green.

(3) The three curves for the yellow show a wide range of selections, with a preference for the red, purple and blue-green sections. There is an exception in the tints and shades with themselves, where there are no marked elevations in the purple. In the colours with themselves there is a decided preference for the blue, but in the colours with the shades, and the shades with themselves, the maxima are in the yellow and yellow-green respectively.

(4) The three figures for yellow-green show a transition from yellow-green in the colours with tints to red in shades with themselves. In the combinations of tints and colours there are high prominences at both the red and the green, but in the saturated series the highest peaks stand at red, red and yellow. respectively, for the three curves. The fourth series has greater diversity. The shades with themselves have two points of great pleasantness, viz. red and yellow-green.

(5) The zigzag lines for the blue-green in the two figures, CV and CVII, are due to the quality-contrast in the tints, colours and shades, each with themselves, being replaced by the contrast of intensity in the series tints and shades with the colours. Whilst the line for the maxima in the middle blue (Fig. CVI) does not have the same shape as those of the other two blues, yet a line joining the points of high preference would resemble them. The great pleasantness in series four (C. S.) at the

purple section is a feature also seen in the curves for yellow-green, blue-green and blue.

(6) In the blue the zigzag curves are quite regular (if the points of high preference in Fig. CVI, C. S., be included in the curve). The bases of the two triangles are in the warm complementary yellow, and their apices in the cold part of the spectrum. (See discussion above in reference to complementary curves for blue, p. 25, rule 3.)

(7) The triangular features remain in the violet curves, though in the shades with the colours there are also maxima at the left of the complementary. The apices here fall at violet (and in C. S. at yellow-green also), and the bases of the triangles at or near the yellow. It may be stated here that, though we have not shown in these curves the positions which the maxima of the series shades with tints, and vice versa, would occupy, they definitely corroborate the testimony of those series above in which there is considerable intensity-contrast (viz. colours with shades and tints), that intensity-contrast may replace that of quality.

(8) In reference to the curves for purple, we observe that they are similar to those for violet, though they differ in the fourth series (S. C.), where in the curve for purple the maxima fall within the yellow and green.

In reference to the relation of red and green a series of experiments upon two "colour-blind" persons may be reported here. After a variety of tests, both were found to be abnormal in their judgments regarding red and green—apparently being dichromates with the neutral zone in the green. One observer chose a rose-coloured yarn to indicate the colour of the clear sky, the other not distinguishing the red flowers from the foliage, while both manifested a liking for bright red neckties and clothes of more or less dark green shades. When the series of saturated colours (combined with themselves) was exhibited, the colours chosen most frequently as pleasant were just those in which the abnormality manifested itself. The results of the trials are shown in curve CXVII, drawn similarly to those for normal observers. Why red and green, which they often do not distinguish, should be chosen as the agreeable sections of the spectrum, it is difficult to say. Aside from the question why

certain affective tones accompany certain colours and their combinations, we have here the problem, What is the colour? If it cannot be demonstrated that two normal persons looking at the same coloured card under similar circumstances and calling it by the same name, e.g. red, do really see the same quality, much less can it be shown what quality other persons see who act and speak of it in an unusual manner, i.e. whom we call "colour-blinds." We can only interpret their words in terms of our own colour-experience. If their red and green were as our grey, we might expect their choices to correspond, to some extent, with Chown's results with greys. On the contrary, her maxima are decidedly at red and blue. If where we see red and green they see a colour of diminished or increased intensity, we should not be surprised if the curves were more closely to follow the figures above where difference of intensity is evident, e.g. S. T. and T. S. (Figs. LXXXV to XCII), where red is less prominent. The selections made rather correspond to the curves for shades with themselves where the red is of high value (Figs. LXIX to LXXVII).

SUMMARY.

1. The present experiments tend to confirm Miss Baker's conclusion that the traditional view regarding the preference for complementaries in colour combinations is unfounded. However, the case of yellow and blue demands some special consideration, perhaps on account of the remaining intensity contrast between those colours when the contrast of saturation has been eliminated.

2. In trials other than those with fully saturated colours the yellow yields its general pre-eminence to yellow-green, though in those series which combine saturated colours with tints or shades both yellow and green are prominent.

3. There seems to be a consensus of judgment that colours of great contrast (though not complementaries) and colours of small intervals form pleasant combinations. (*a*) When there is a considerable intensity and saturation contrast the tendency is toward the small interval of quality (e.g. shades with tints, etc.). (*b*) When the saturation contrast is practically eliminated and the intensity contrast largely reduced, for instance, in colours, tints or shades each combined with themselves, the wide interval aesthetically predominates (e.g. between yellow-green and red). The remaining intensity difference between yellow and blue, when these colours are of equal saturation, seems to add to, rather than to replace, the value of the quality contrast, thereby giving the above-mentioned peculiarity. This conclusion may throw some light upon Kirschmann's statement that our sense of sight seems to find pleasure in combinations with a great contrast effect, to which Külpe makes reference in his report.* Kirschmann also claims that small quality intervals are pleasant.†

4. Our trials show conclusively that Purkinje's phenomenon plays an important rôle in the selection of pleasant combina-

* *Bericht über den II. Kongress f. exp. Psych.*, p. 27.

† University of Toronto Studies, Psych. Series I. 415, footnote.

tions throughout the different series. The present investigation of the phenomenon gives definite information in reference to Brücke's contention that "small intervals please if the distribution of intensity and the difference of quality correspond to the natural effect of shadow."*

5. The polar sections appear to be yellow adjacent to the green, and violet-blue, instead of yellow or orange-yellow, and blue (as in Miss Baker's paper).

6. The present experiments not being confined to highly and equally saturated colours as in Miss Baker's work, but including variety of intensity and of saturation, may be applied more widely to practical purposes, though there is yet to be considered the influence of variation of size, shape and position. These further possibilities are now being investigated in the Psychological Laboratory.

* Baker, op. cit., p. 37.

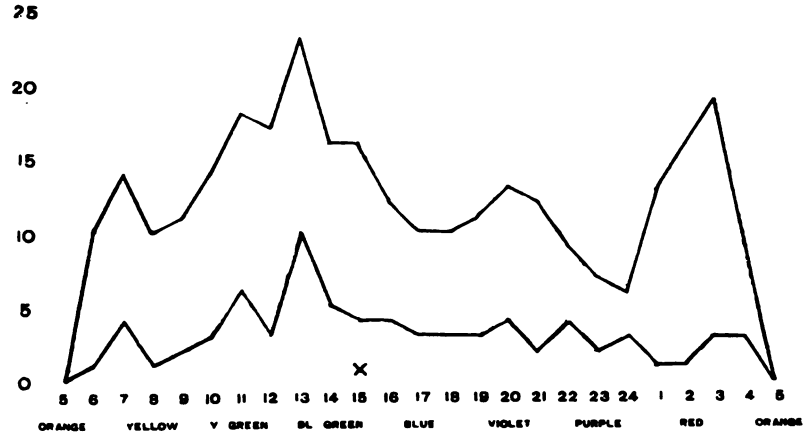


FIG. XXIII.—ORANGE, TINT 5 WITH TINTS

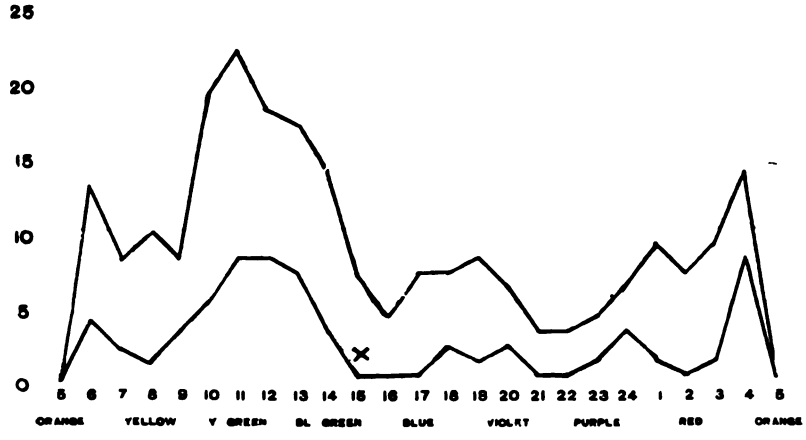


FIG. XXIV.—ORANGE, SHADE 5 WITH SHADES

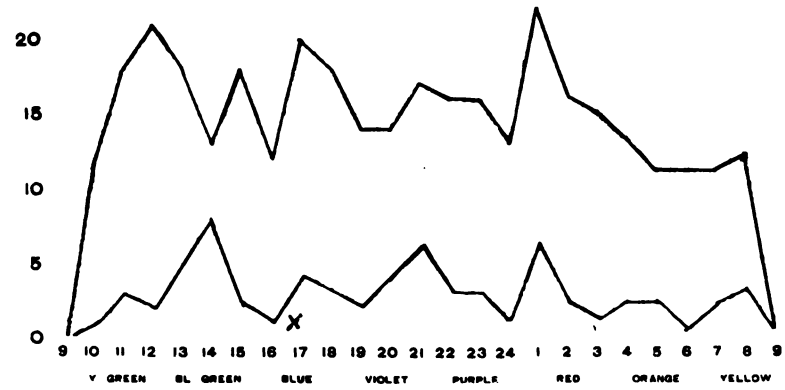


FIG. XXV.—YELLOW, TINT 9 WITH TINTS

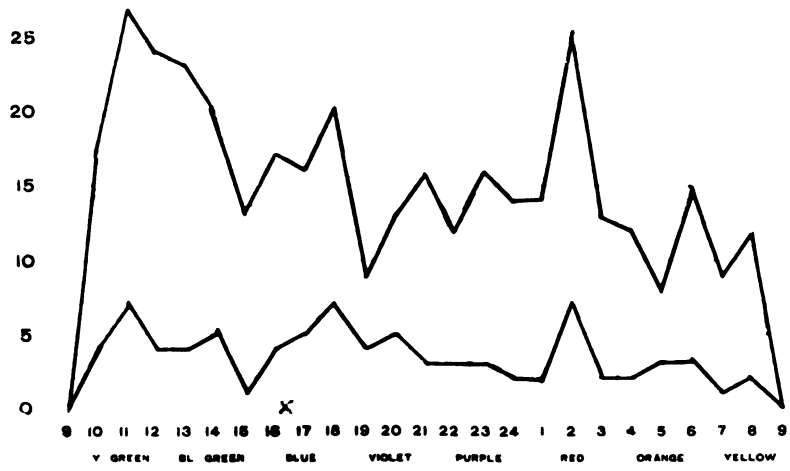


FIG. XXVI.—YELLOW, SHADE 9 WITH SHADES

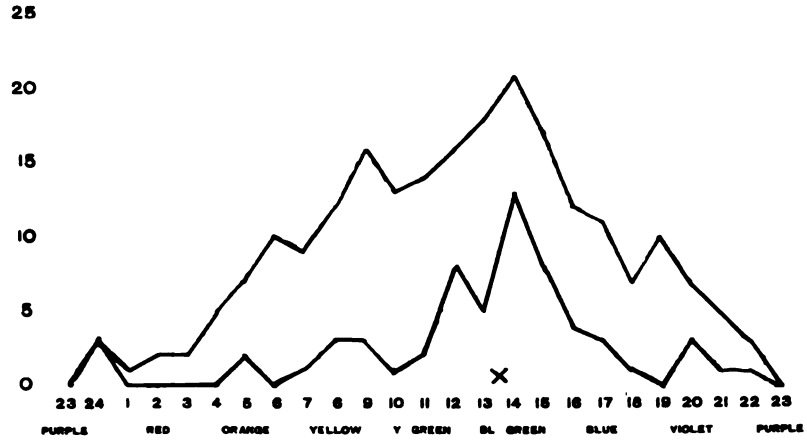


FIG. XXVII.—PURPLE 23, TINTS WITH TINTS

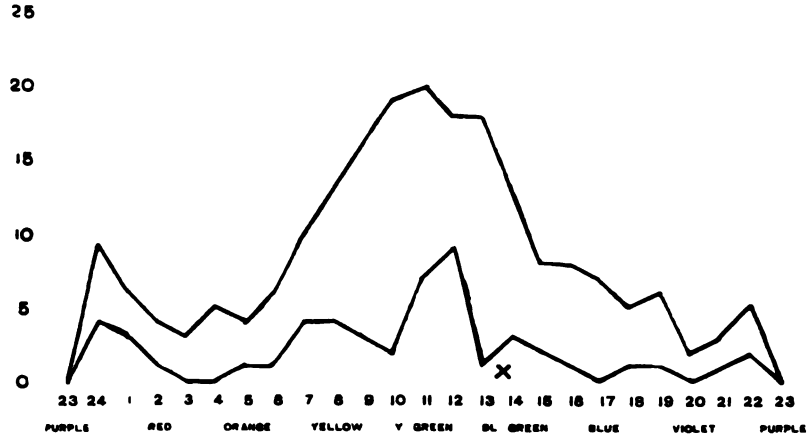


FIG. XXVIII.—PURPLE 23, SHADES WITH SHADES

FIG. XXIX.—RED 1, SHADES AND TINTS

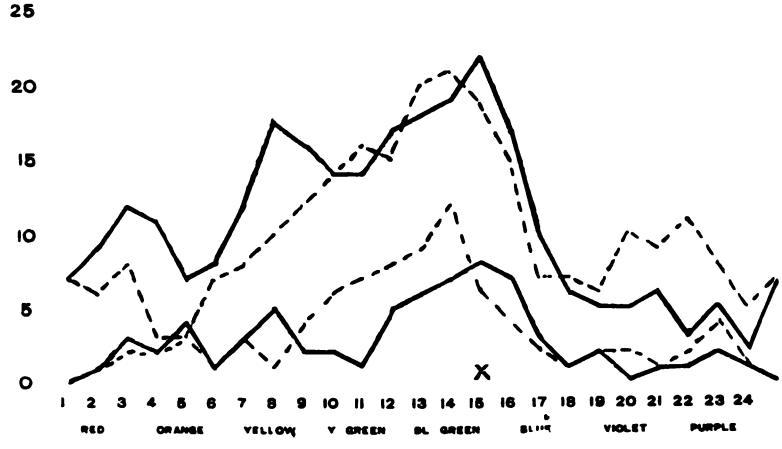


FIG. XXX.—PURPLE 23, SHADES AND TINTS

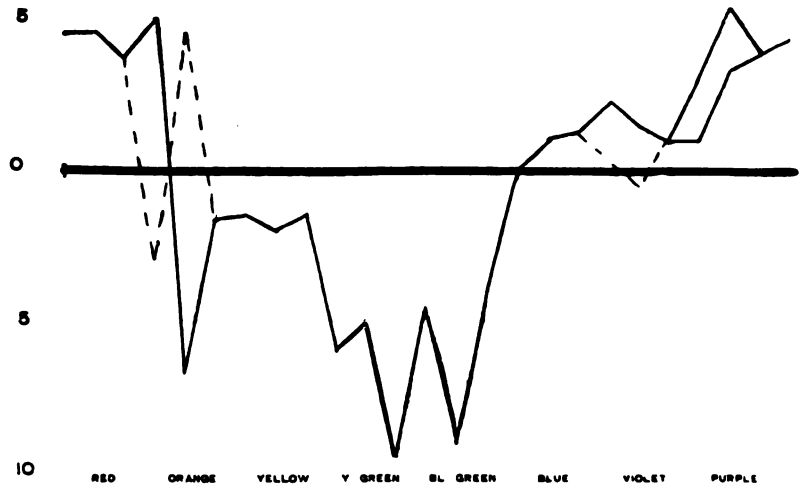


FIG. XXXI.—COLOURS WITH COLOURS

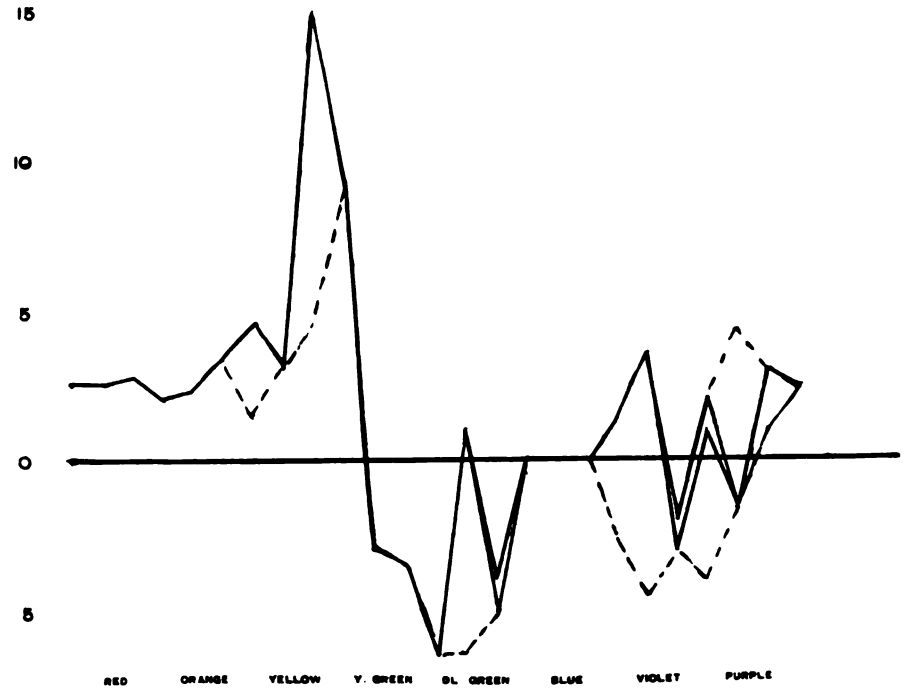


FIG. XXXII.—TINTS WITH TINTS

[redacted]

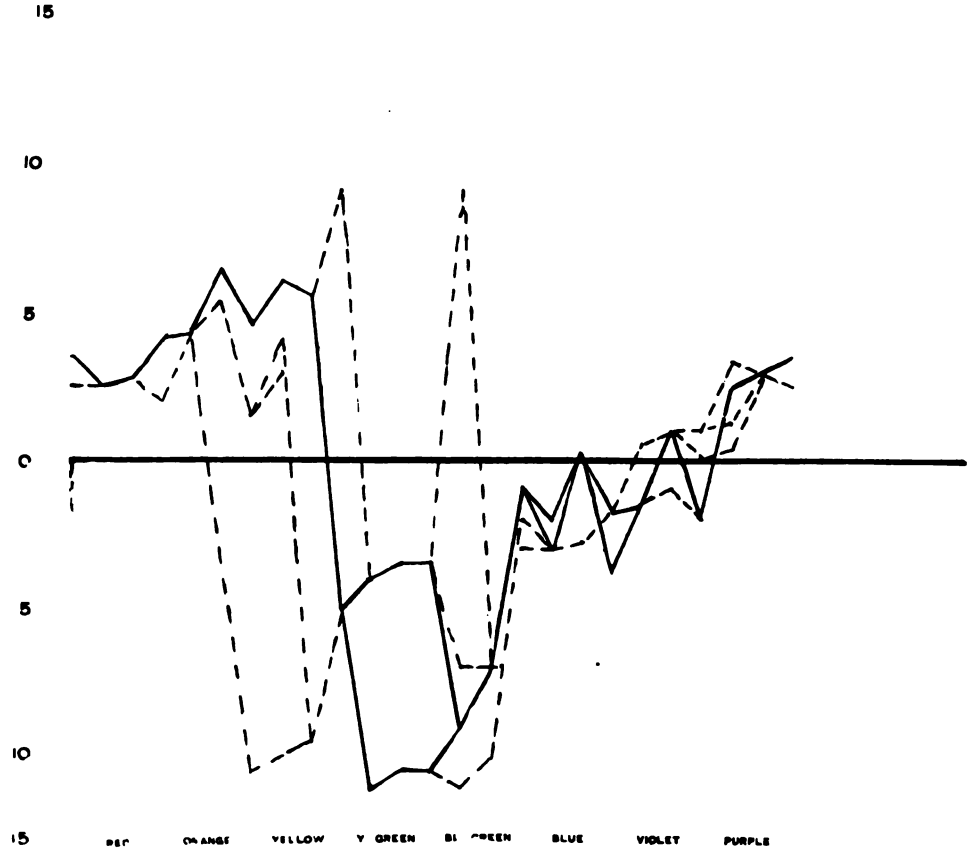


FIG. XXXIII.—SHADES WITH SHADES

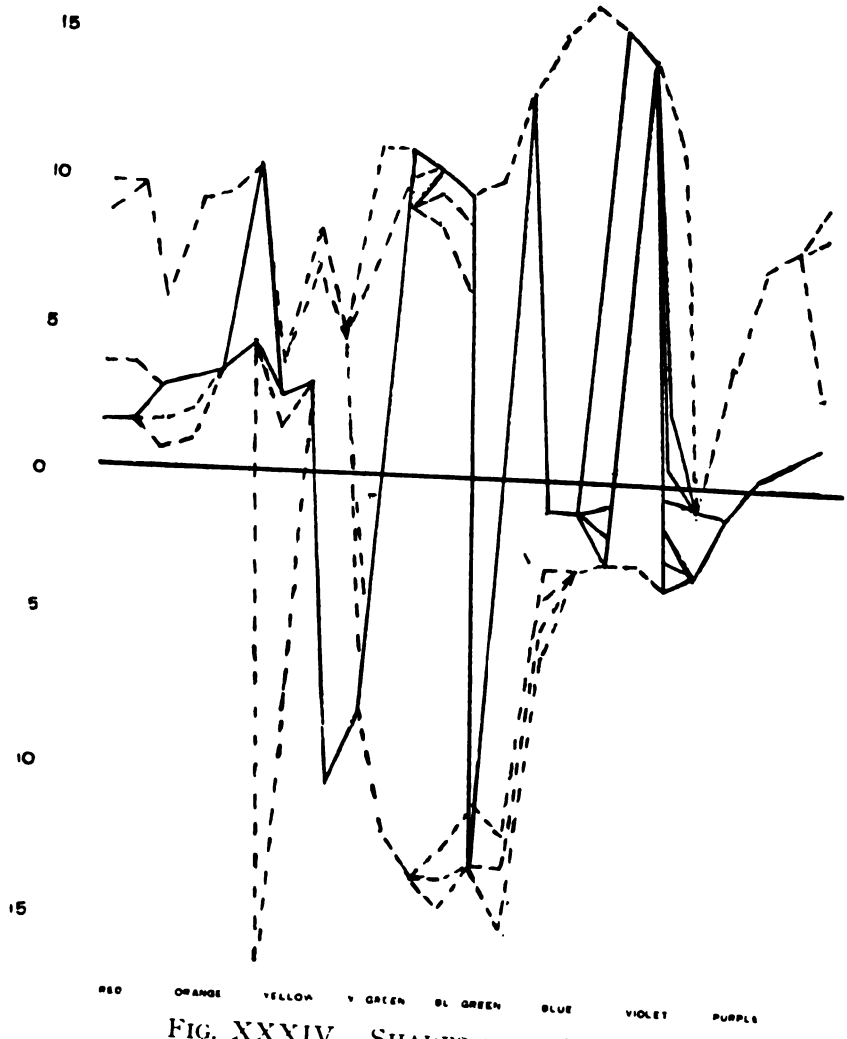


FIG. XXXIV.—SHADES WITH TINTS

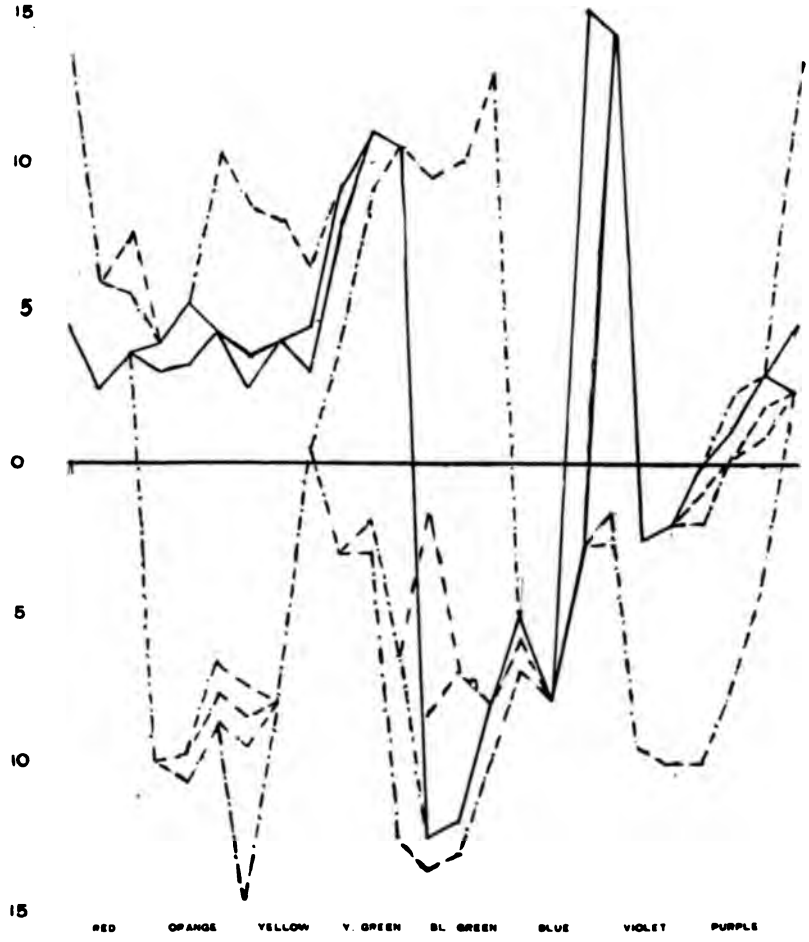


FIG. XXXV.—TINTS WITH SHADES

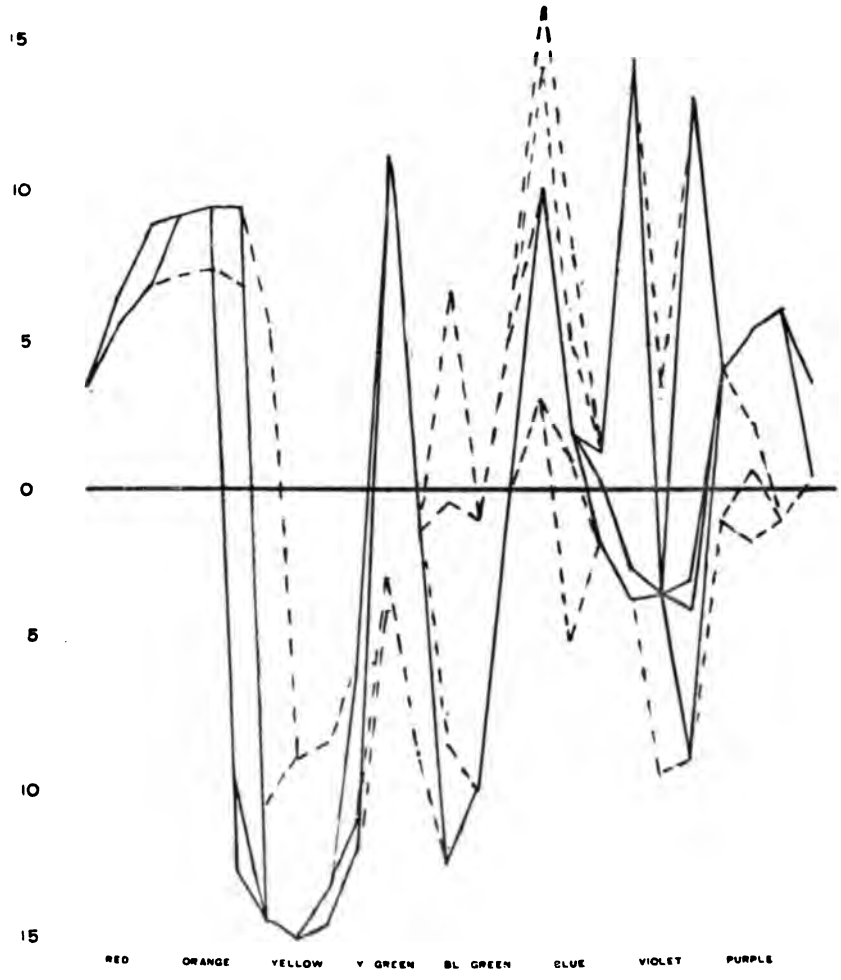


FIG. XXXVI.—COLOURS WITH SHADES

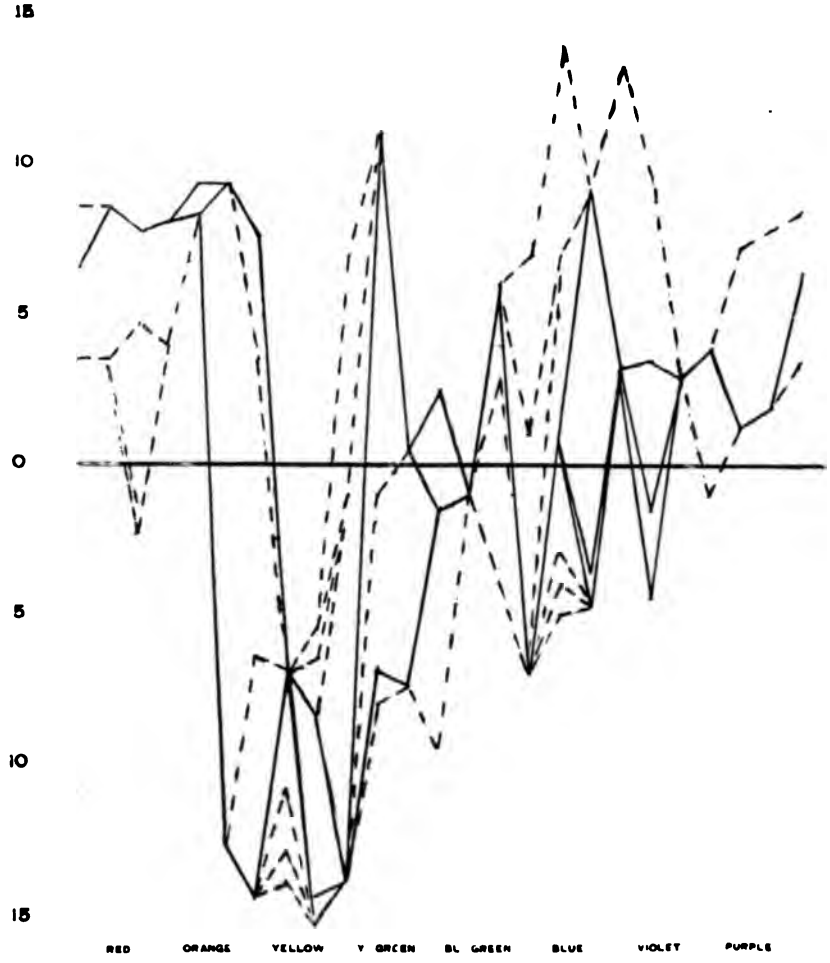


FIG. XXXVII.—SHADES WITH COLOURS

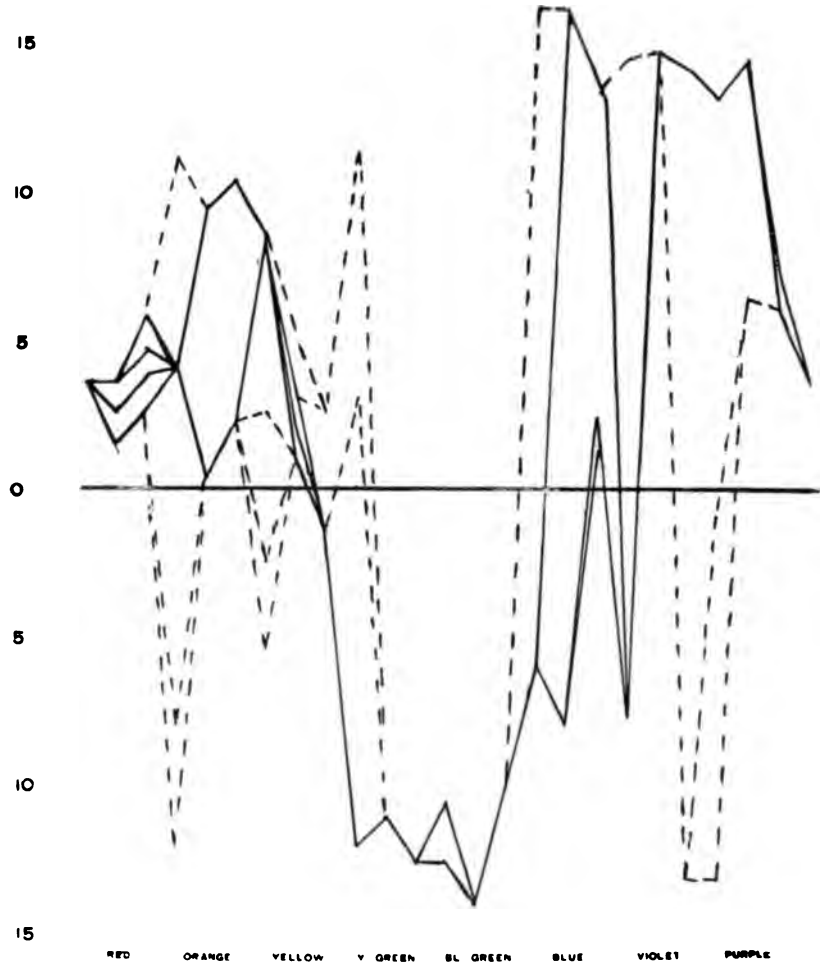


FIG. XXXVIII.—COLOURS WITH TINTS

[redacted]

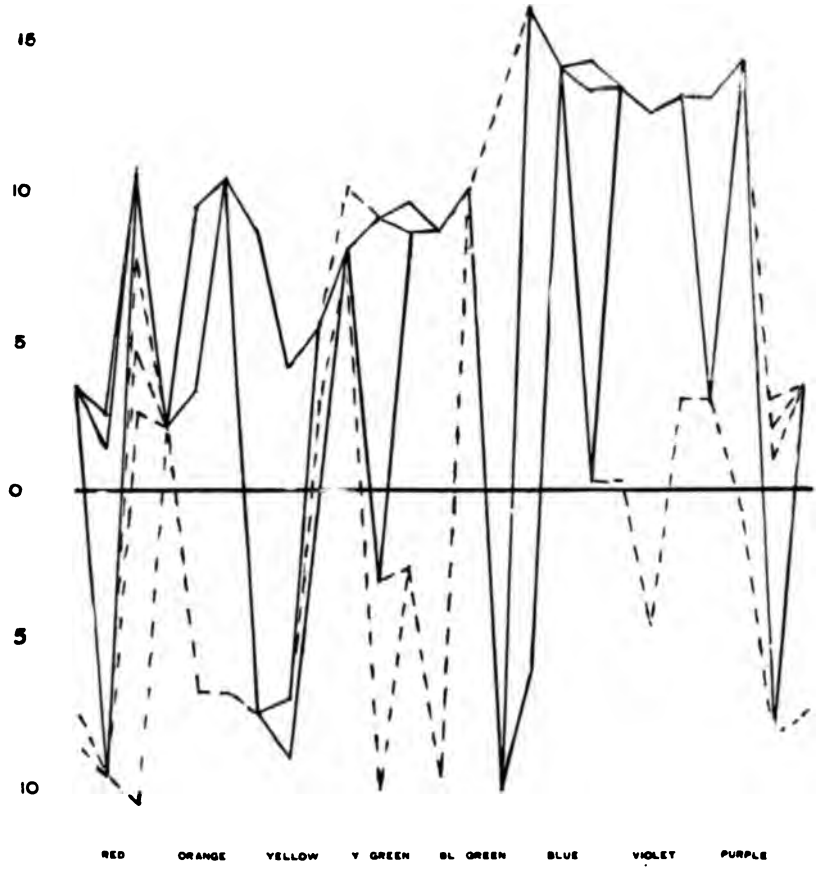


FIG. XXXIX.—TINTS WITH COLOURS

FIG. XL.—INTENSITY CONTRAST

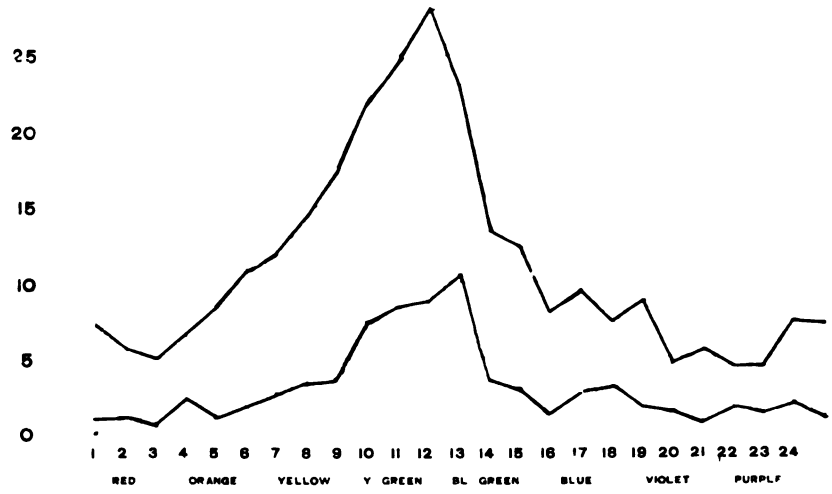


FIG. XLI.—RED, SHADES 1, 2, 3

FIG. XLII.—RED, TINTS 1, 2, 3

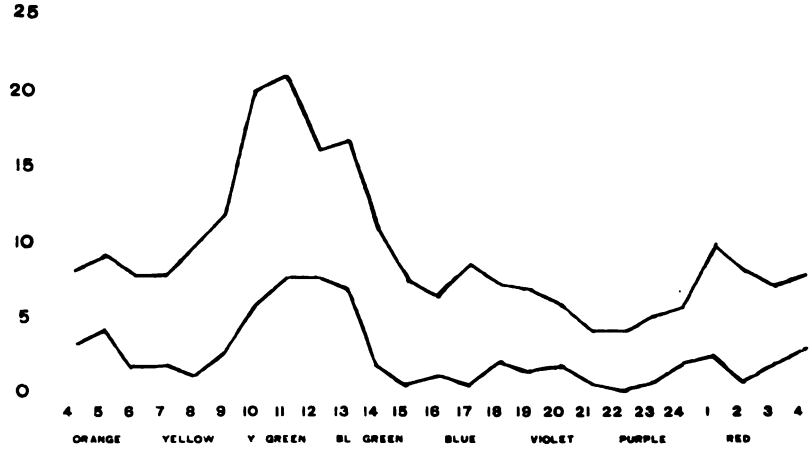


FIG. XLIII.—ORANGE, SHADES 4, 5, 6

FIG. XLIV.—ORANGE, TINTS 4, 5, 6

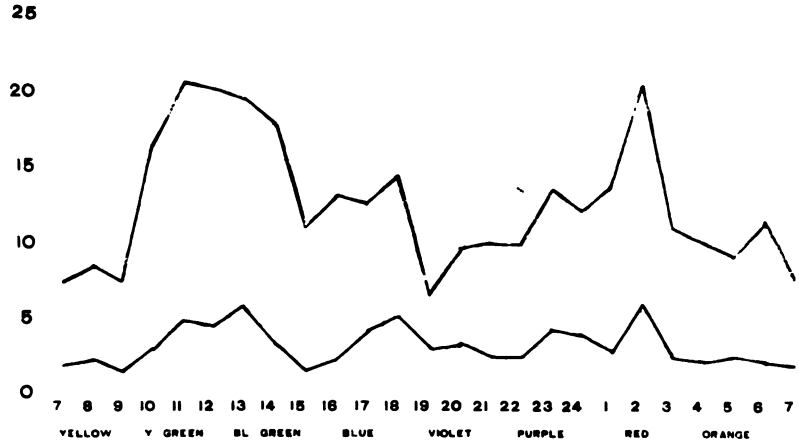


FIG. XLV.—YELLOW, SHADES 7, 8, 9

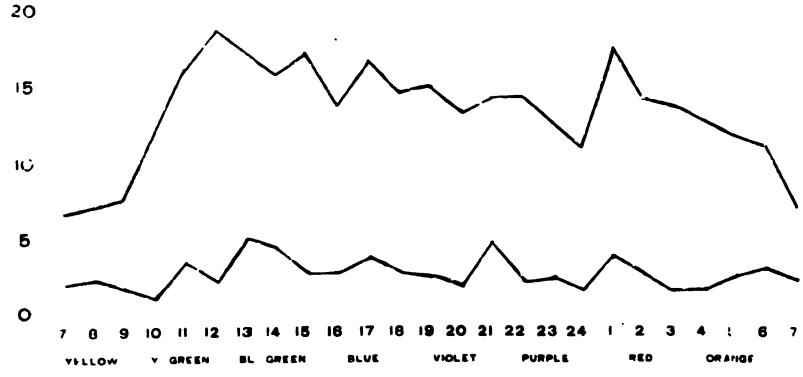


FIG. XLVI.—YELLOW, TINTS 7, 8, 9

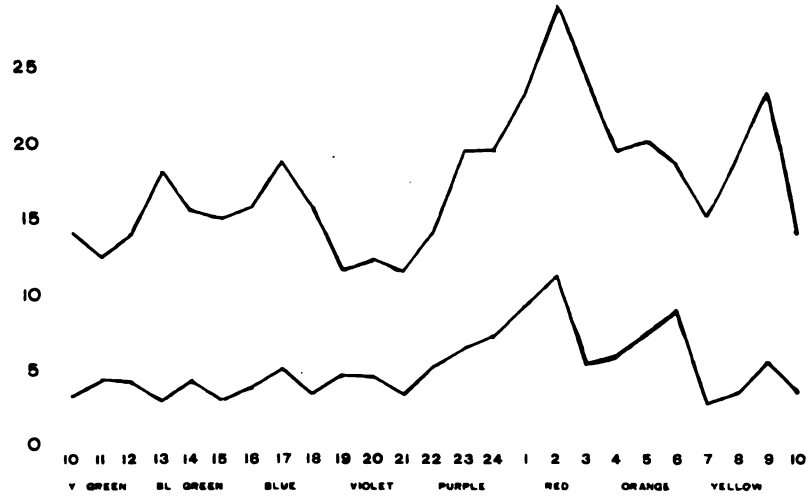


FIG. XLVII.—YELLOW-GREEN, SHADES 10, 11, 12

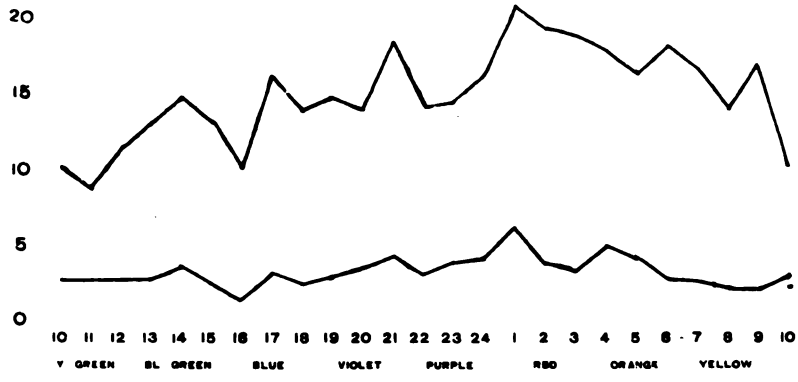


FIG. XLVIII.—YELLOW-GREEN, TINTS 10, 11, 12

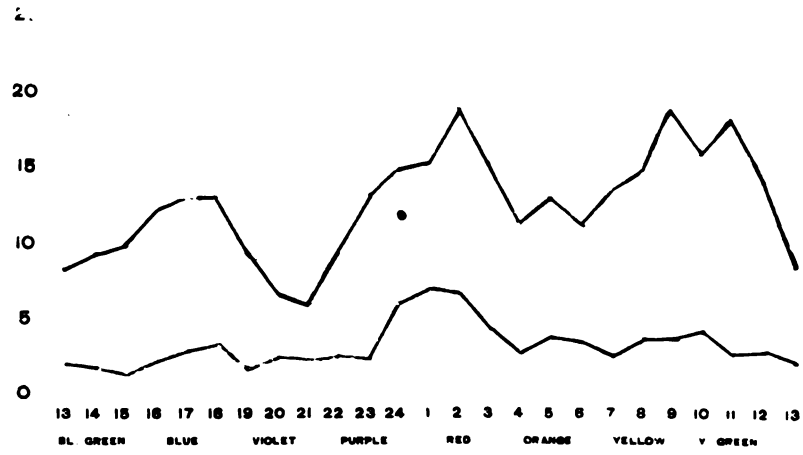


FIG. XLIX.—BLUE-GREEN, SHADES 13, 14, 15

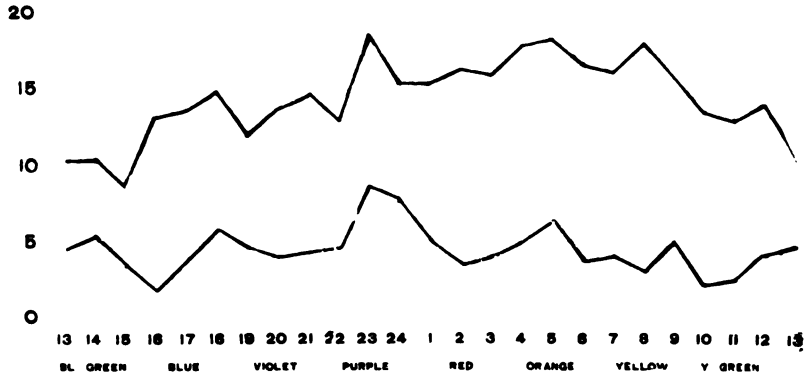


FIG. L.—BLUE-GREEN, TINTS 13, 14, 15

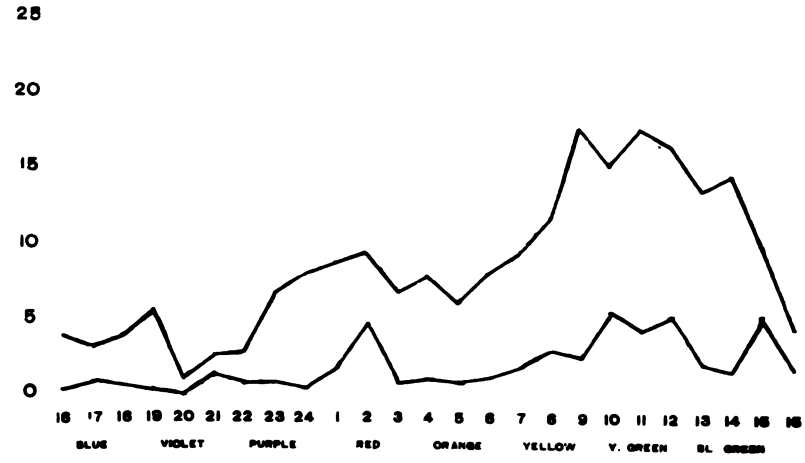


FIG. LI.—BLUE, SHADES 16, 17, 18

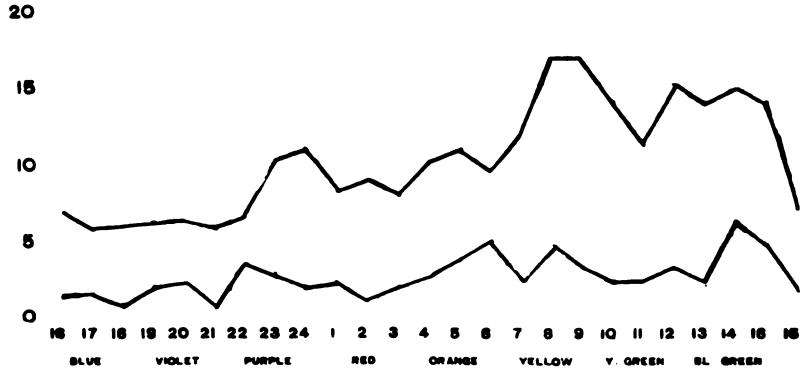


FIG. LII.—BLUE, TINTS 16, 17, 18

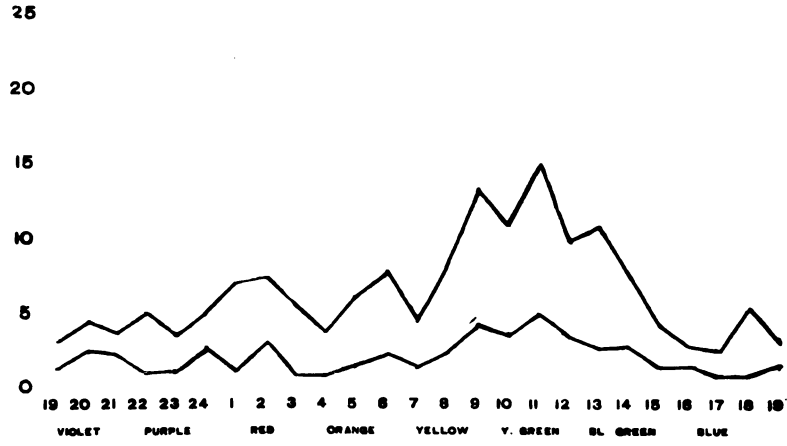


FIG. LIII.—VIOLET, SHADES 19, 20, 21

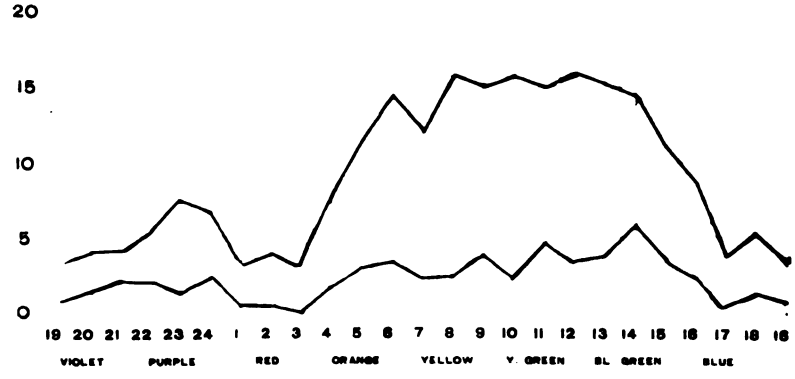


FIG. LIV.—VIOLET, TINTS 19, 20, 21

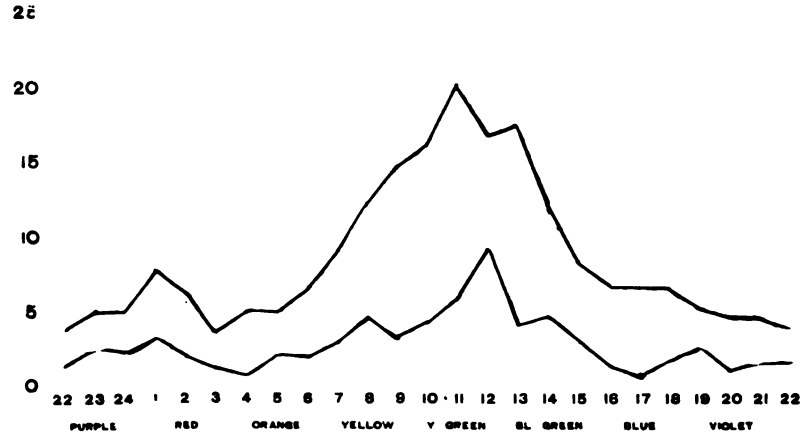


FIG. LV.—PURPLE, SHADES 22, 23, 24

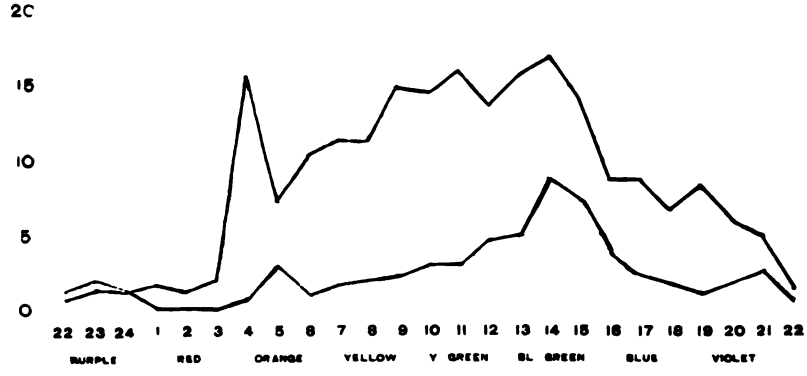


FIG. LVI.—PURPLE, TINTS 22, 23, 24

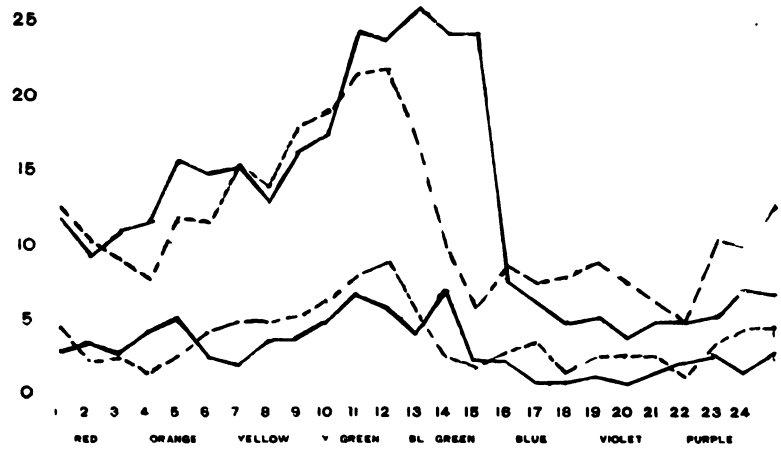


FIG. LVII.—RED, SHADES AND TINTS 1, 2, 3

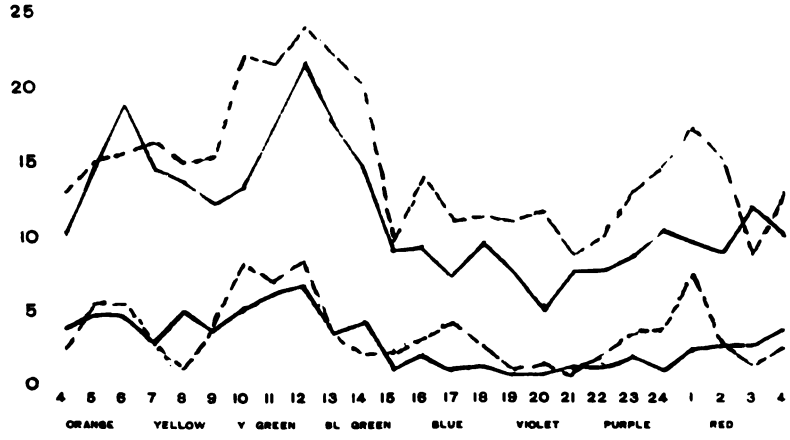


FIG. LVIII.—ORANGE, SHADES AND TINTS 4, 5, 6

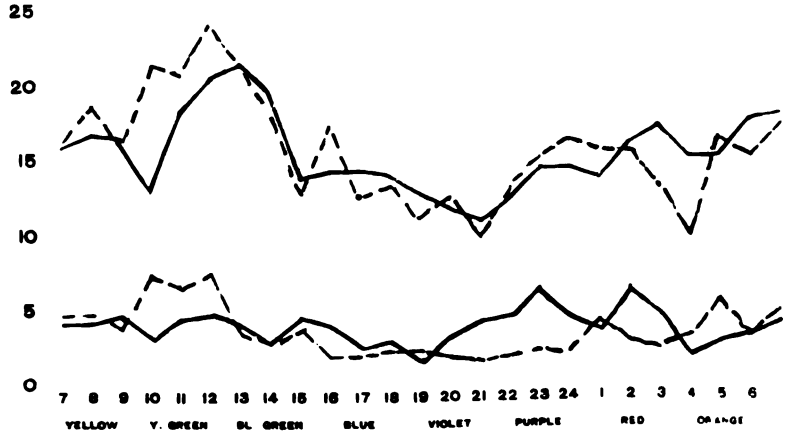


FIG. LIX.—YELLOW, SHADES AND TINTS 7, 8, 9

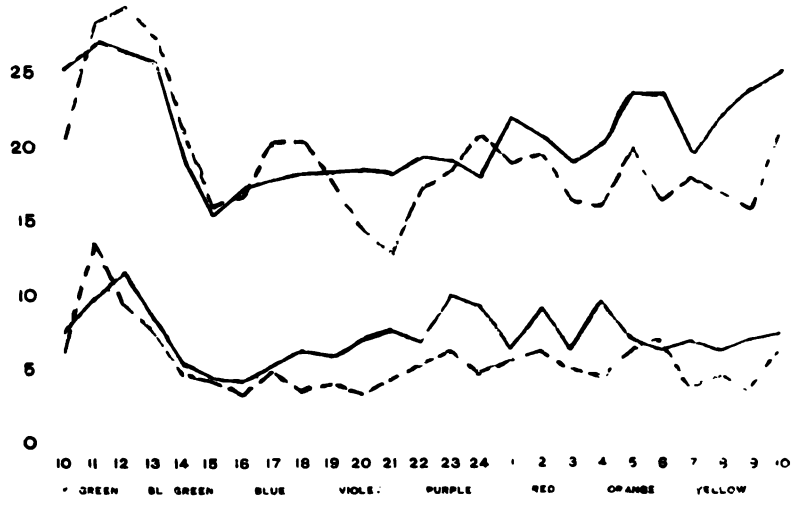


FIG. LX.—YELLOW-GREEN, 10, 11, 12

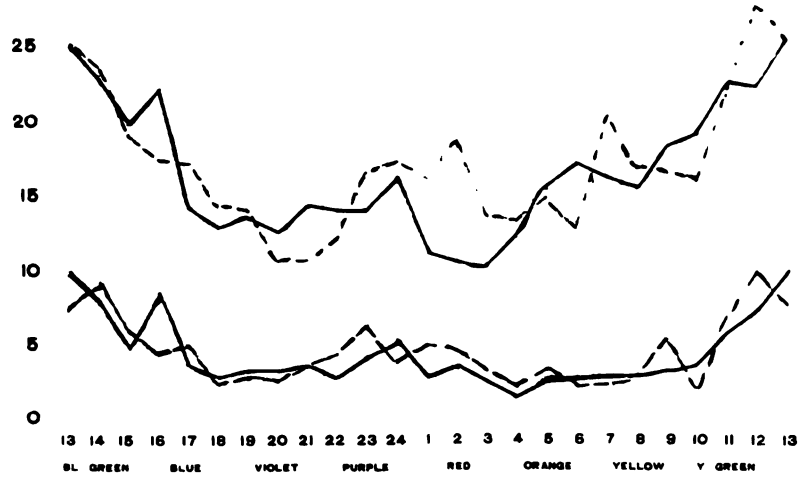


FIG. LXI.—BLUE-GREEN, 13, 14, 15

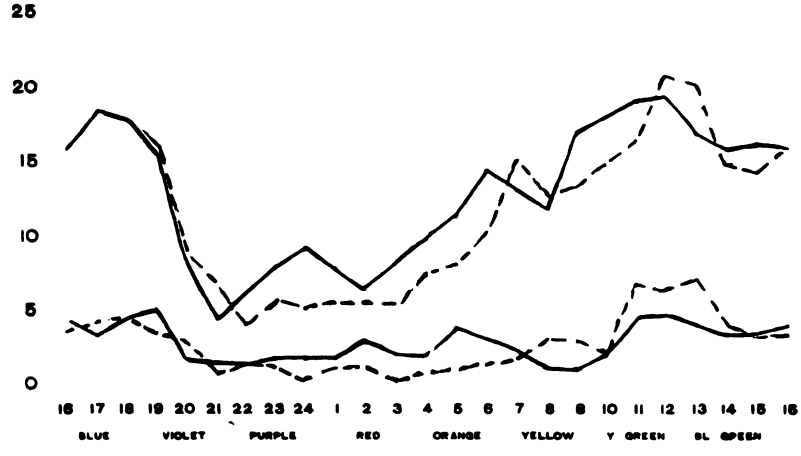


FIG. LXII.—BLUE, 16, 17, 18

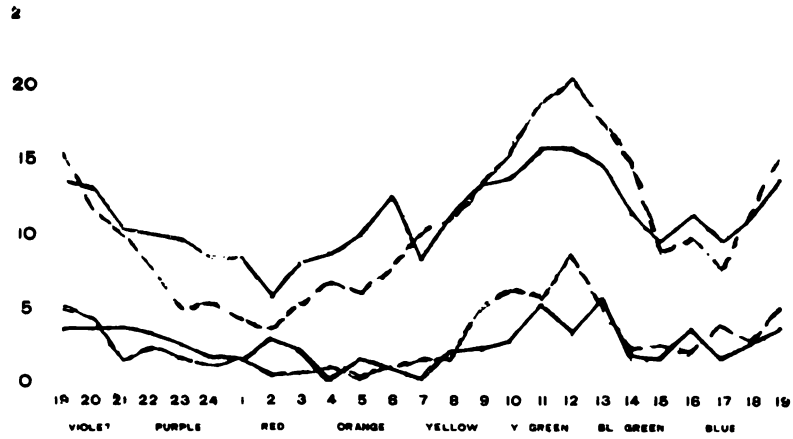


FIG. LXIII.—VIOLET, 19, 20, 21

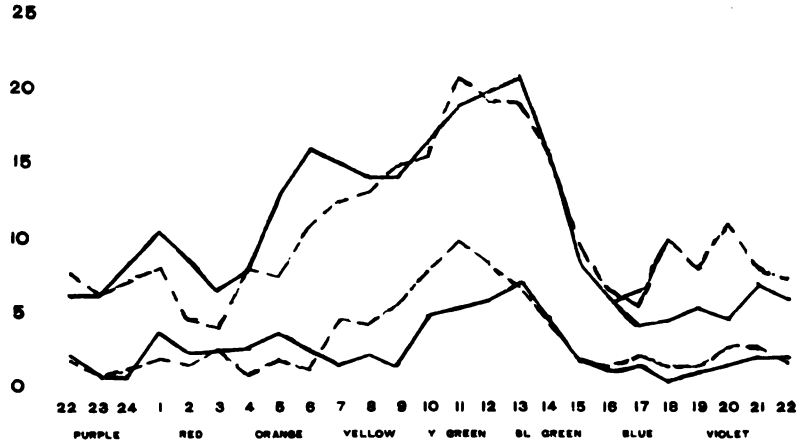


FIG. LXIV.—PURPLE, 22, 23, 24

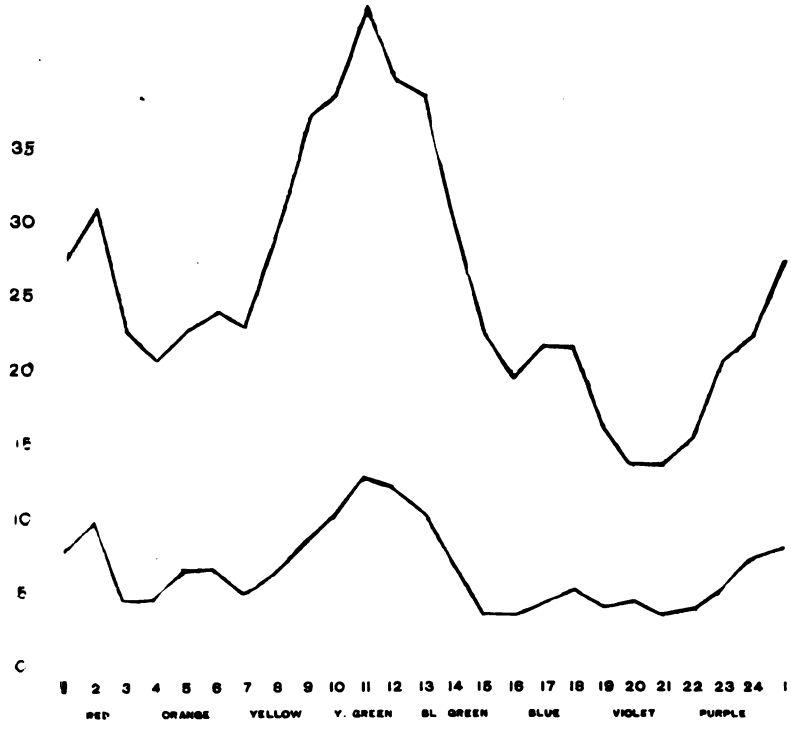


FIG. LXV.—SHADES

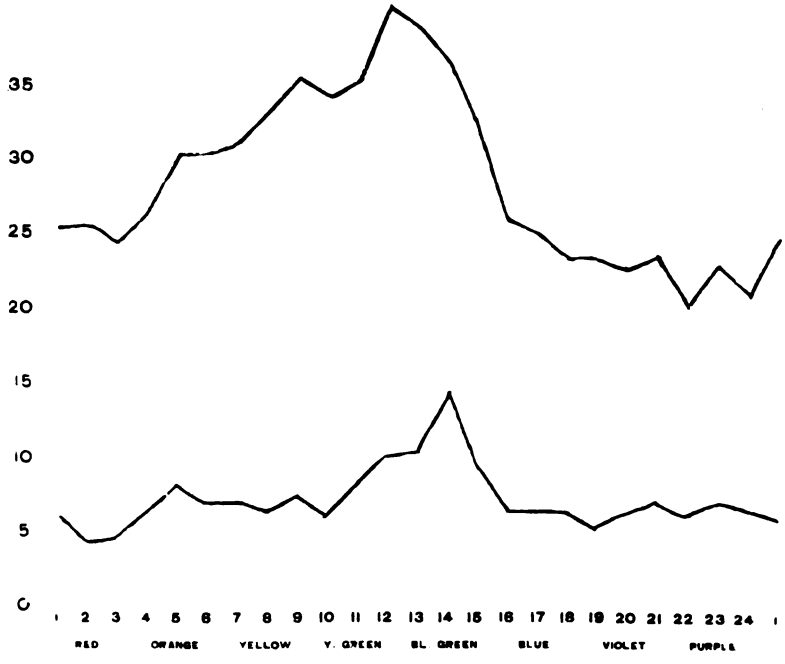


FIG. LXVI.—TINTS

TOTAL CURVES

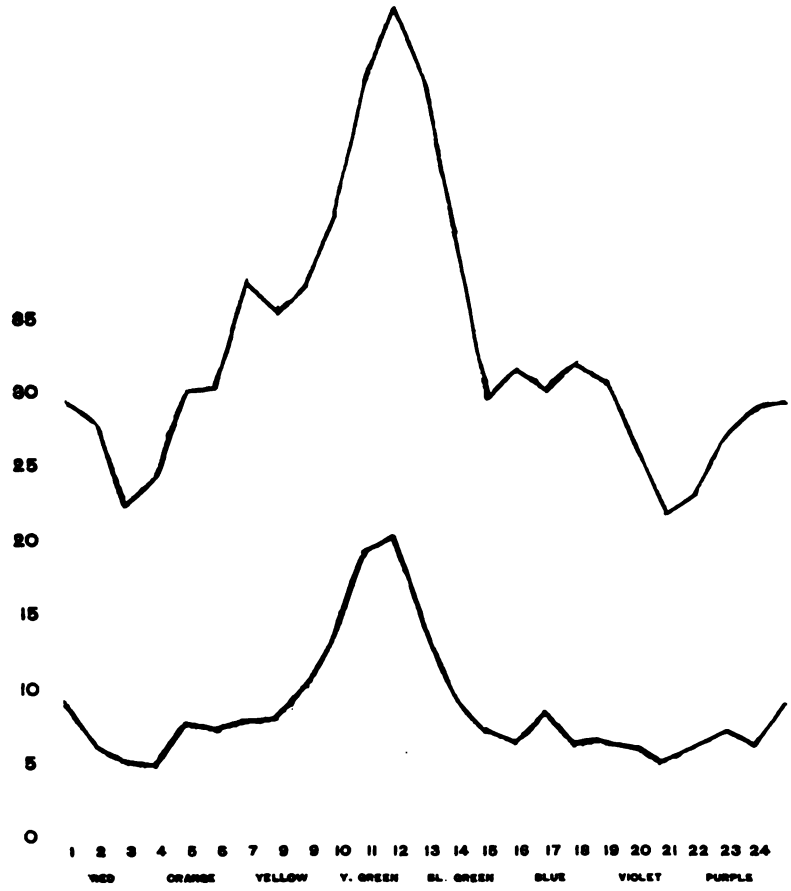


FIG. LXVII.—SHADES WITH TINTS

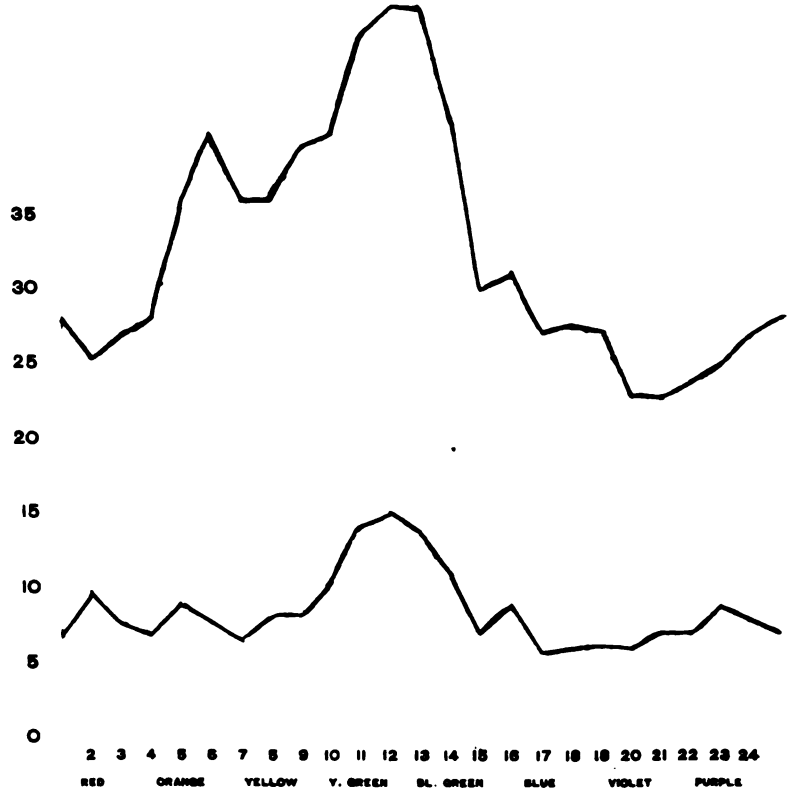


FIG. LXVIII.—TINTS WITH SHADES
TOTAL CURVES

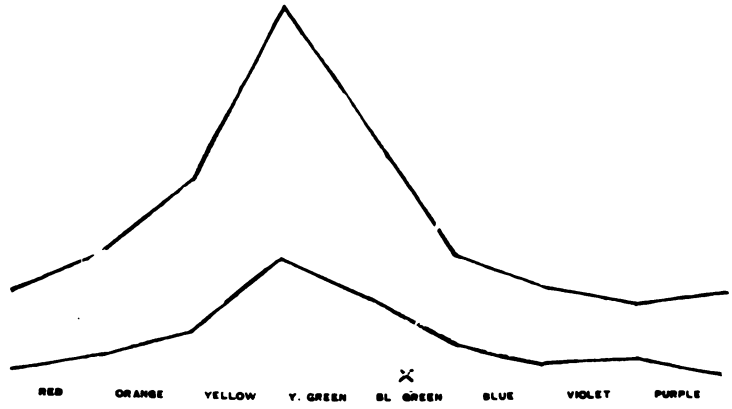


FIG. LXIX.—RED

FIG. LXX.—ORANGE

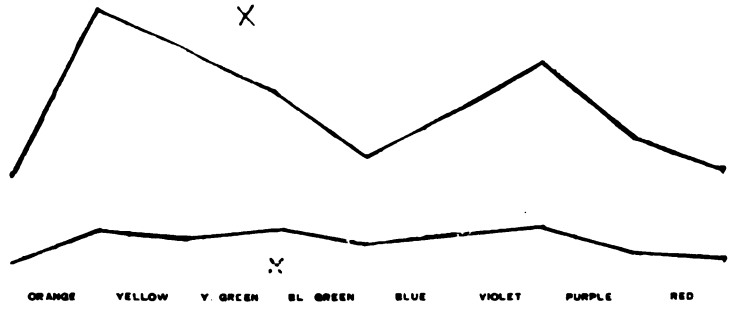


FIG. LXXI.—YELLOW

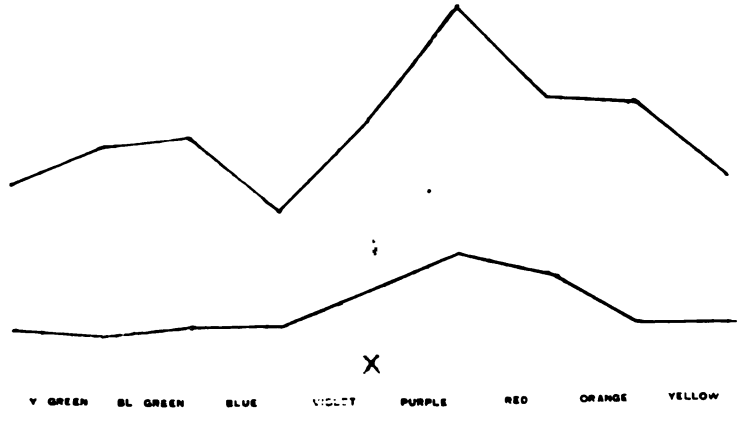


FIG. LXXII.—YELLOW-GREEN
SUMMATION CURVES—SHADES

FIG. LXXIII.—BLUE-GREEN

FIG. LXXIV.—BLUE

FIG. LXXV.—VIOLET

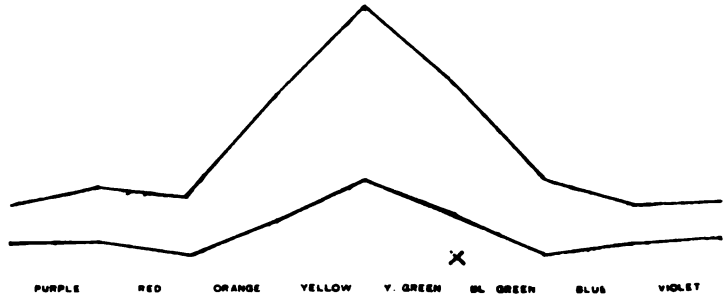


FIG. LXXVI.—PURPLE

SUMMATION CURVES—SHADES

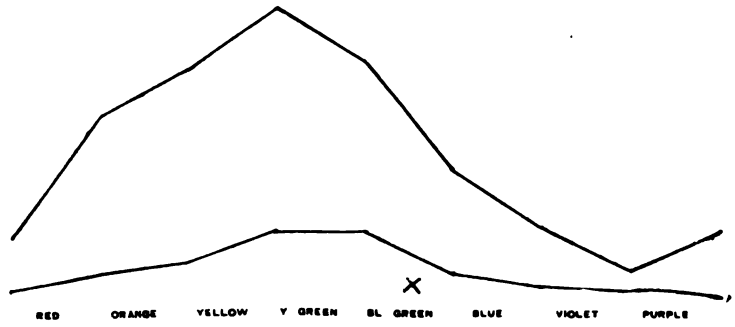


FIG. LXXVII.—RED

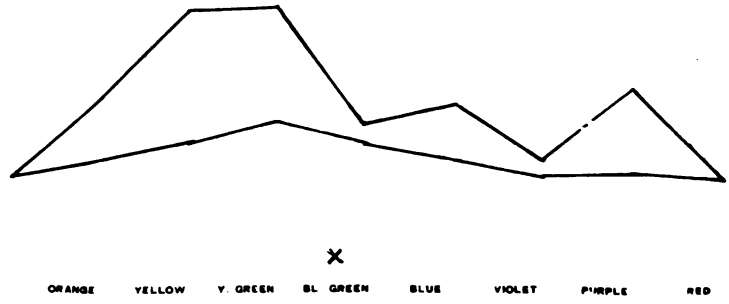


FIG. LXXVIII.—ORANGE

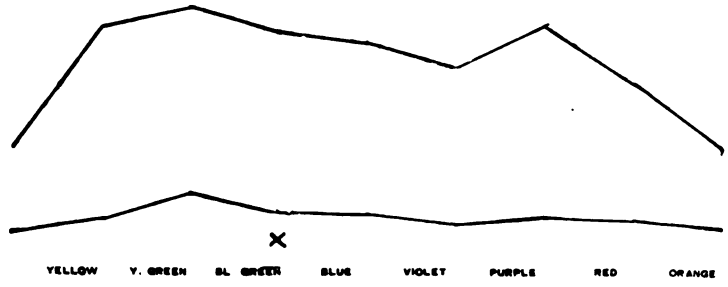


FIG. LXXIX.—YELLOW

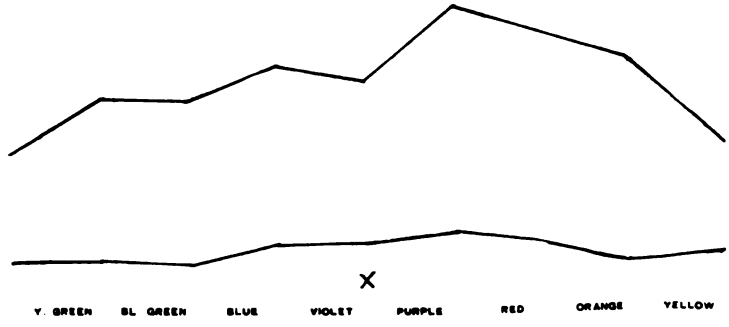


FIG. LXXX.—YELLOW-GREEN

SUMMATION CURVES—TINTS

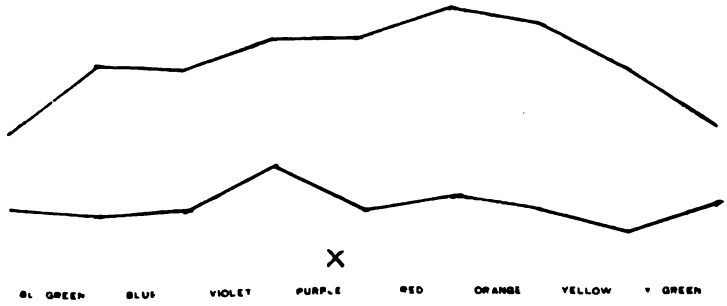


FIG. LXXXI.—BLUE-GREEN

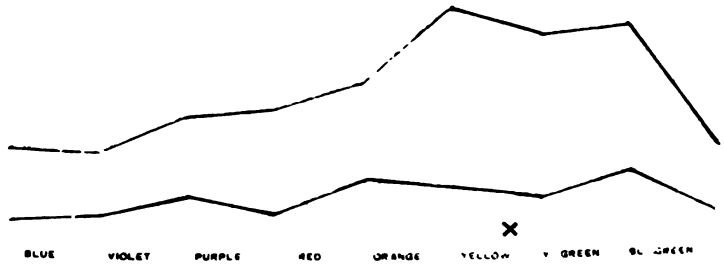


FIG. LXXXII.—BLUE

FIG. LXXXIII.—VIOLET

FIG. LXXXIV.—PURPLE

SUMMATION CURVES—TINTS

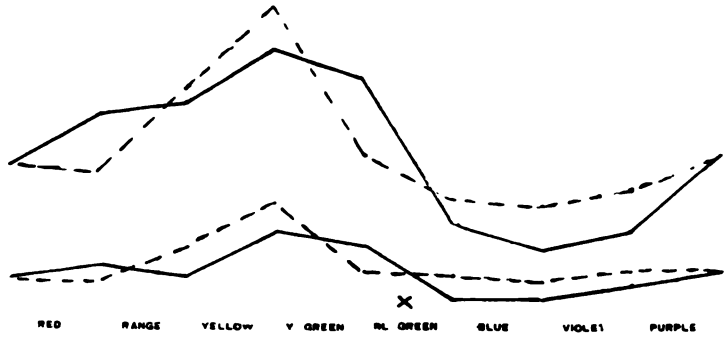


FIG. LXXXV.—RED

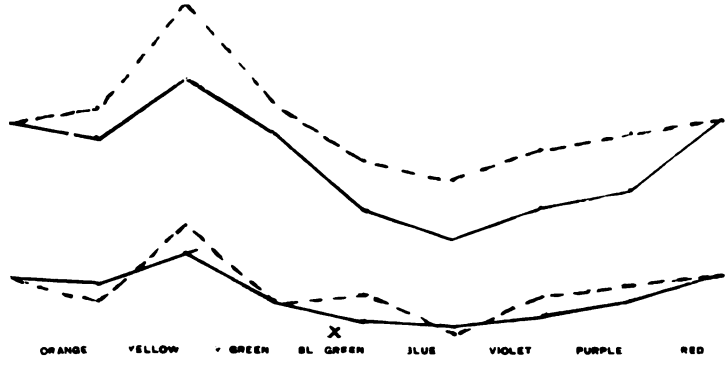


FIG. LXXXVI.—ORANGE

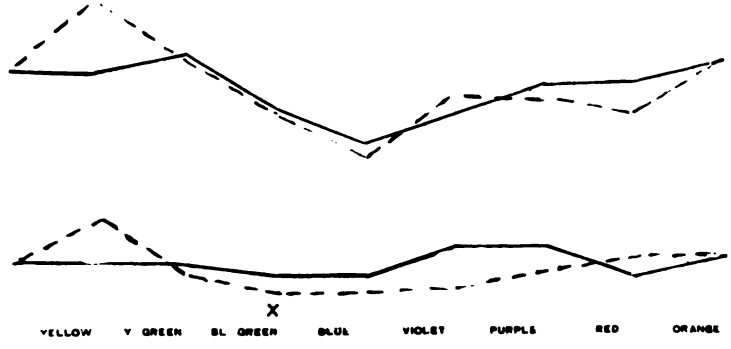


FIG. LXXXVII.—YELLOW

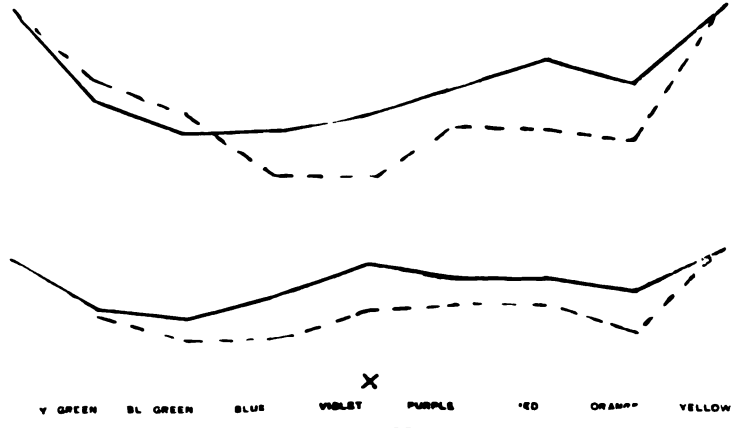


FIG. LXXXVIII.—YELLOW-GREEN

SUMMATION CURVES—SHADES AND TINTS

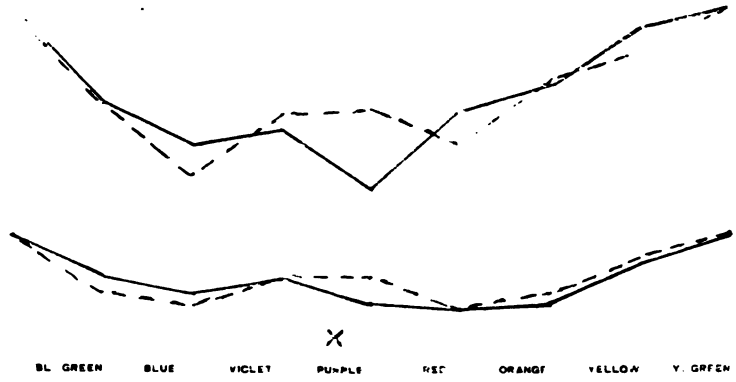


FIG. LXXXIX.—BLUE-GREEN

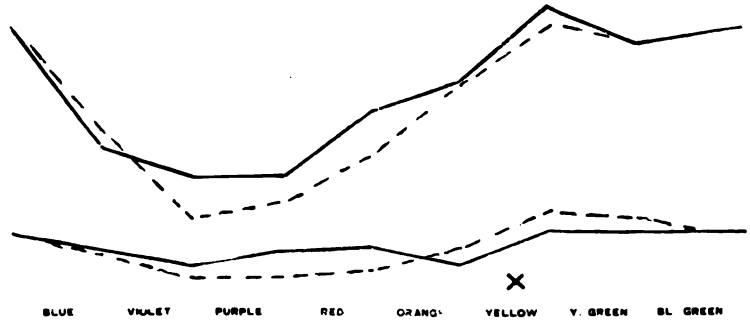


FIG. XC.—BLUE

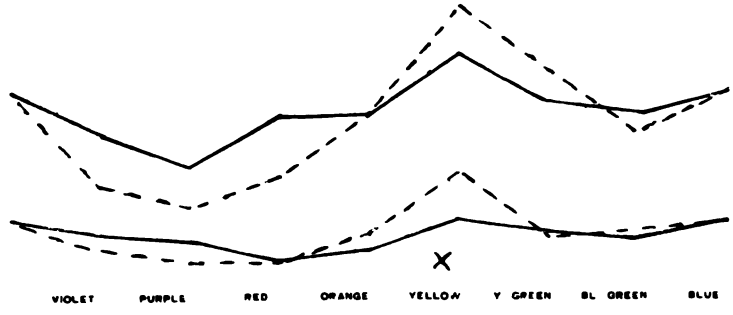


FIG. XCI.—VIOLET

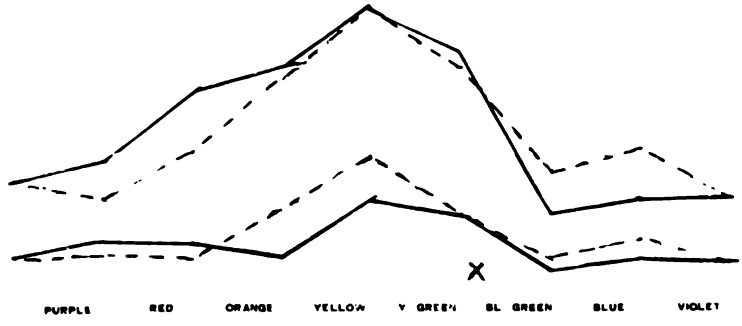


FIG. XCII.—PURPLE

SUMMATION CURVES—SHADES AND TINTS

COMPARISON OF THE FIVE SERIES.

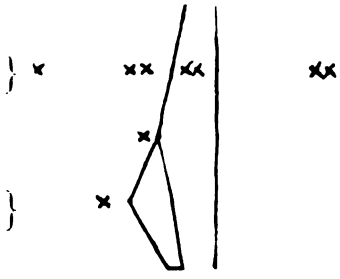


FIG. XCIII.—RED 1.

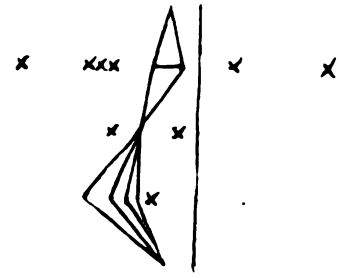


FIG. XCIV.—RED 2.

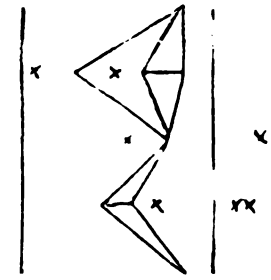


FIG. XCV.—RED 3.

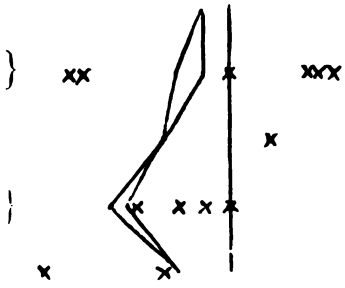


FIG. XCVI.—ORANGE 4.

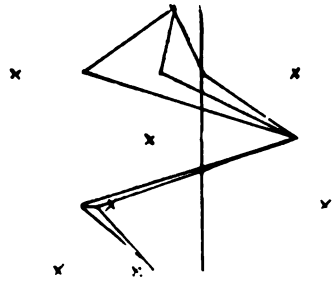


FIG. XCVII.—ORANGE 5.

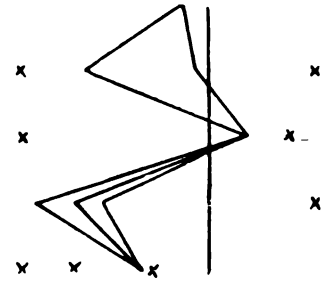


FIG. XCVIII.—ORANGE 6

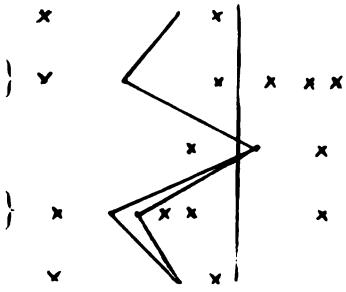


FIG. XCIX.—YELLOW 7.

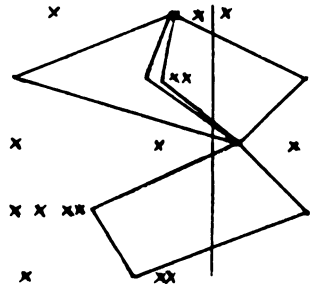


FIG. C.—YELLOW 8.

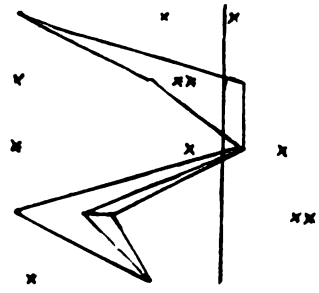


FIG. CI.—YELLOW 9.

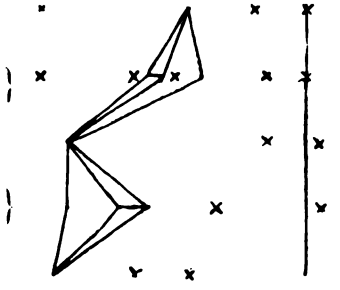


FIG. CII.—YEL.-GREEN 10.

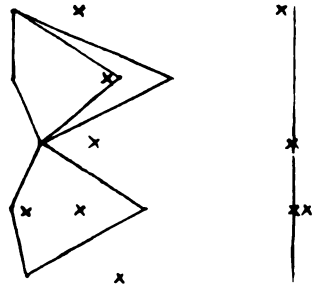


FIG. CIII.—YEL.-GREEN 11.

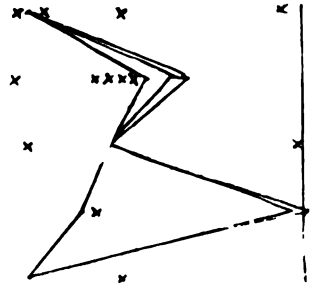


FIG. CIV.—YEL.-GREEN 12.

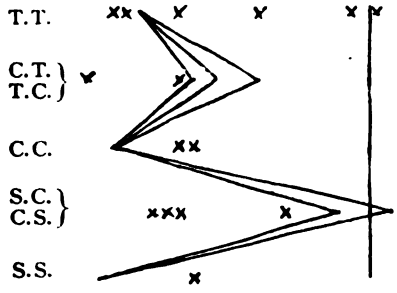


FIG. CV.—BLUE-GREEN 13.

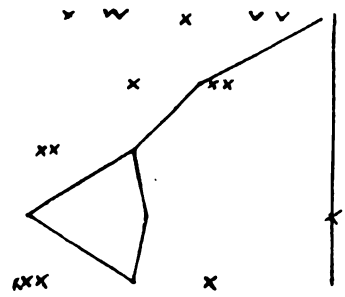


FIG. CVI.—BLUE-GREEN 14.

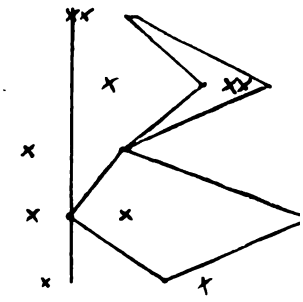


FIG. CVII.—BLUE-GREEN

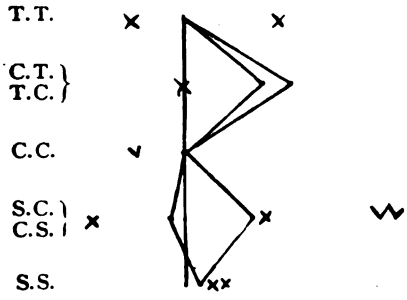


FIG. CVIII.—BLUE 16.

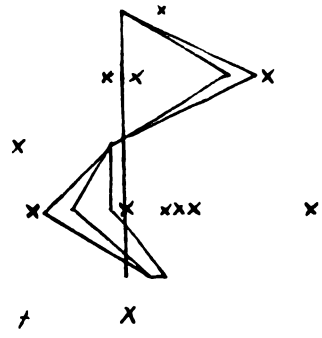


FIG. CIX.—BLUE 17.

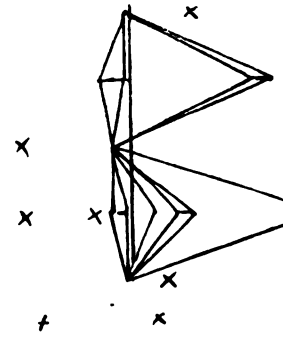


FIG. CX.—BLUE 18

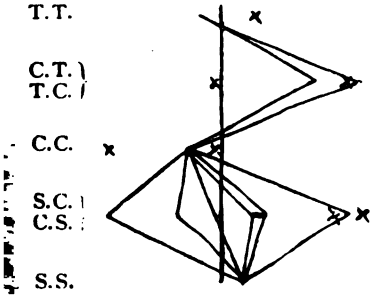


FIG. CXI.—VIOLET 19.

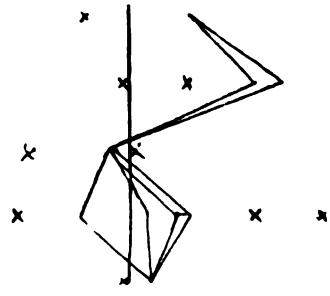


FIG. CXII.—VIOLET 20.

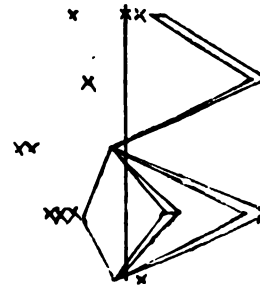


FIG. CXIII.—VIOLET

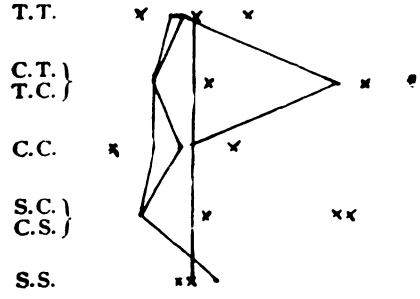


FIG. CXIV.—PURPLE 22.

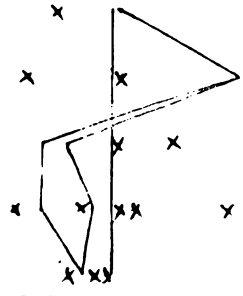


FIG. CXV.—PURPLE 23.

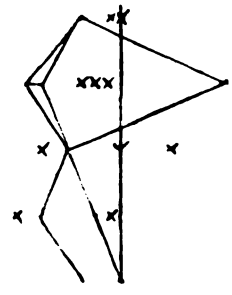
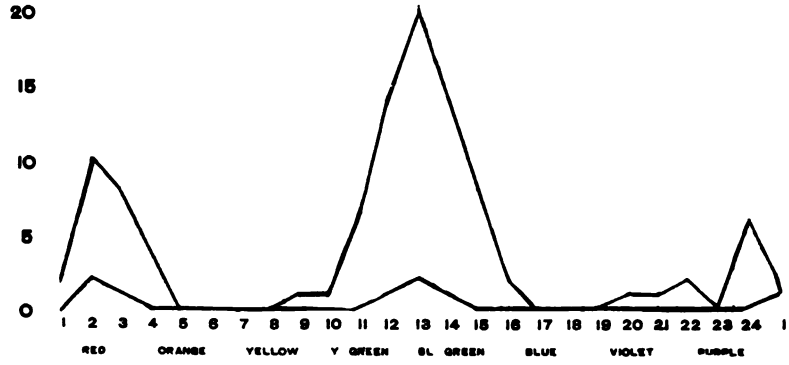


FIG. CXVI.—PURPLE



ABNORMAL A.

ABNORMAL B.

FIG. CXVII.

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BINARY COMBINATIONS OF TINTS AND SHADES AMONG THEMSELVES AND WITH ONE ANOTHER, BY F. LOUIS BARBER.

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